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PEDCo-Environmental, Inc., Cincinnati, OH

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EVALUATION OF PILOT - SCALE AIR POLLUTION CONTROL DEVICES ON A MUNICIPAL WATERWALL INCINERATOR

by

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ABSTRACT

This project report discusses the results of a program for the testing of two pilot-scale air pollution control devices, a fabric filter, and a venturi scrubber at the Braintree, Massachusetts Municipal Solid Waste Incinerator. It includes operation, sampling, and analytical efforts and outlines the plant operating conditions at the time of testing of the two pilot control devices. The Braintree Municipal Incinerator is a mass-burn, water-wall type consisting of two furnaces, each designed to burn 4.7 Mg (5 tons) per hour of unprocessed refuse.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This research report entails the operation of two pilot-scale air pollution control devices on a mass-burn, water-wall type incinerator which burned unprocesses refuse. The pilot-scale devices tested were a fabric filter and a Venturi scrubber.

The information contained herein will be of interest to those designers or users who are contemplating or working with a system similar to the Braintree system. Requests for further information regarding the production and utilization of refuse-derived fuel should be directed to the Thermal Destruction Branch, HWERL, Cincinnati.

David G. Stephan, Director
Hazardous Waste Engineering Research Laboratory

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PEDCo wishes to recognize the contributions of the Industrial Environmental Research Laboratories in Cincinnati, Ohio, and Research Triangle Park, North Carolina; Metcalf and Eddy, Inc.; and the City of Braintree personnel involved with the project (Mr. Edward Courchene, Mr. Robert Sherman, and Mr. Joseph Clegeet); and Iowa State University.

SECTION 1

INTRODUCTION

This report presents the results of a program for the testing of two pilot-scale air pollution control devices (a fabric filter and a venturi scrubber) at the Braintree, Massachusetts, Municipal Solid Waste Incinerator. PEDCo Environmental, Inc., operated the devices and performed the environmental sampling for the U.S. Environmental Protection Agency under Contract Number 68-02-2509, "Air Pollution Control Technology Development for Waste-as-Fuel Processes." The overall objective of the project was to gather data on air pollution control technology as applied to various waste-as-fuel combustion processes.

The Braintree Municipal Incinerator is a mass-burn, water-wall type consisting of two furnaces, each designed to burn 4.7 Mg (5 tons) per hour of unprocessed refuse. Mixed municipal refuse is delivered by packer truck and cars from Braintree and several other communities in the surrounding area. Air emissions were controlled by an ESP having a design efficiency of 93 percent at 910 actual m^3/min (32,000 acfm) at 320°C (600°F).

PEDCo conducted tests on the pilot fabric filter and venturi scrubber, which were slipstreamed on uncontrolled flue gas from the Unit No. 1 incinerator over sequential time periods. The fabric filter was operated and tested from August 28 to September

14, 1979, and the venturi scrubber, from October 2 to October 12, 1979.

This report includes results of operation, sampling, and analytical efforts and outlines the plant operating conditions at the time of testing of the two pilot control devices. Normal operating conditions of the incinerator were maintained during testing, and no attempt was made to modify them except as required to retain steady-state conditions throughout the testing. The Braintree Plant operated continuously and was very reliable over the entire test program.

Prior to the Braintree test program, similar testing was conducted at the Ames, Iowa, Power Plant. The Ames Power Plant co-fires RDF (refuse-derived fuel) and pulverized coal in a tangential-fired suspension boiler with a design capacity of 35 MW. Three pilot scale control devices were tested at this site. An ESP and scrubber furnished by the Industrial Environmental Research Laboratory at Research Triangle Park (IERL/RTP) and operated by Acurex, were slipstreamed and tested in the fall of 1978. A pilot fabric filter that was designed and fabricated under this project was tested at Ames in the spring and summer of 1979. The fabric filter is the only device that was tested at both the Ames Power Plant and the Braintree Incinerator. The results of the Ames tests are presented in a report entitled "Evaluation of Pilot Scale Air Pollution Control Devices on a Refuse and Coal Fired Boiler."[1]

The remainder of this report is divided as follows. Section 2 describes the facilities, Section 3 presents the test plan, Section 4 describes the pilot equipment, Section 5 presents the test results, Section 6 describes the quality assurance practices, and Section 7 presents the conclusions and recommendations. Appendix A discusses the sampling and analytical methods used, and Appendix B provides photographs of the facilities.

SECTION 2

FACILITIES

The Braintree plant, which began operations in 1971, consists of twin waterwall incinerators, each with a design capacity of 110 Mg (120 tons) of refuse per 24-h period. Each unit is equipped with an ESP for emission control, and both ESP's exhaust to a common stack. Figures 2-1 and 2-2 show a cross section of the incinerator system and a top view of the control equipment configuration.[2]

Municipal refuse brought to the Braintree plant is dumped into a 1020-m^3 (1340-yd^3) receiving pit. Care is taken to remove such bulky items as tires, furniture, and the like, which might jam the incinerator feed hoppers. An overhead crane equipped with a grapple bucket transports the material from the pit to the charging hoppers (one per furnace).

Typical pick loads of the grapple bucket were weighed and found to be approximately 2100 lb during the fabric filter tests and 2500 lb during the scrubber tests. The incinerator was charged with four or five grapple bucket loads per hour.

The town of Braintree generates an average of 90 to 93 Mg (95 to 100 tons) of refuse per day. The accounting records of the incinerator (Figure 2-3) yielded the following source characterization data:

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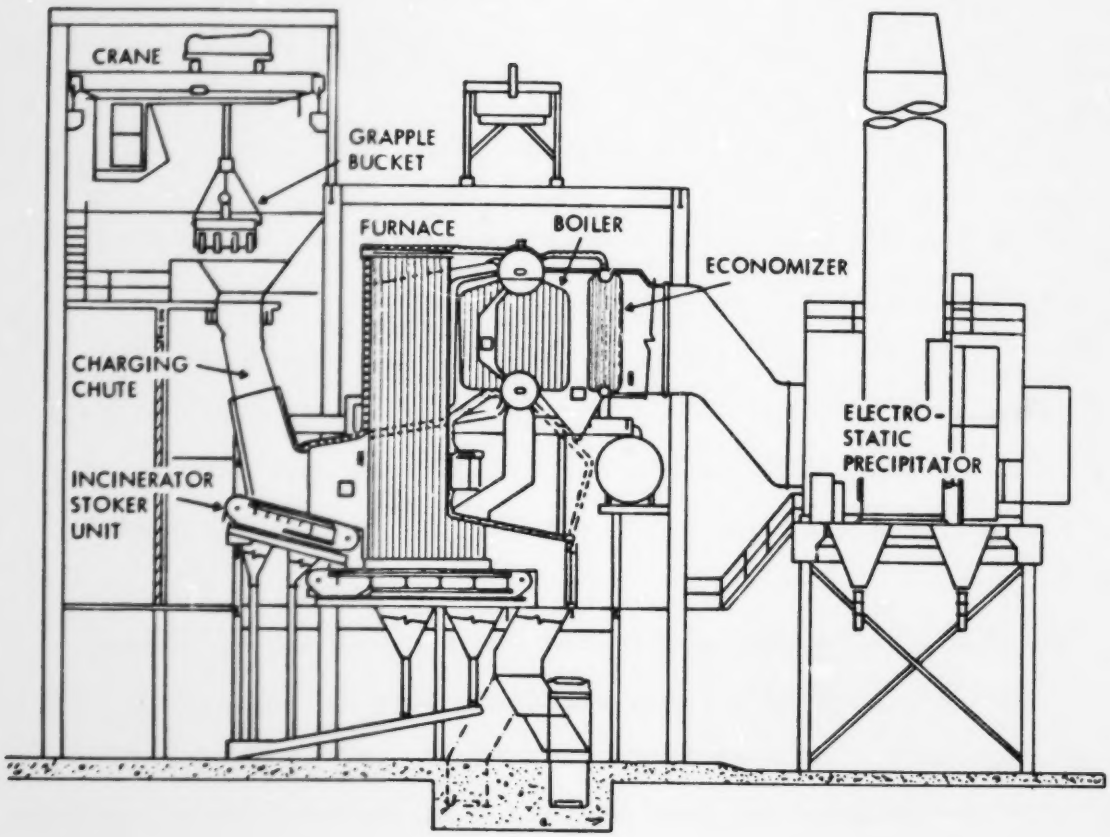

Figure 2-1. Braintree municipal incinerator, Braintree, Massachusetts.[2]

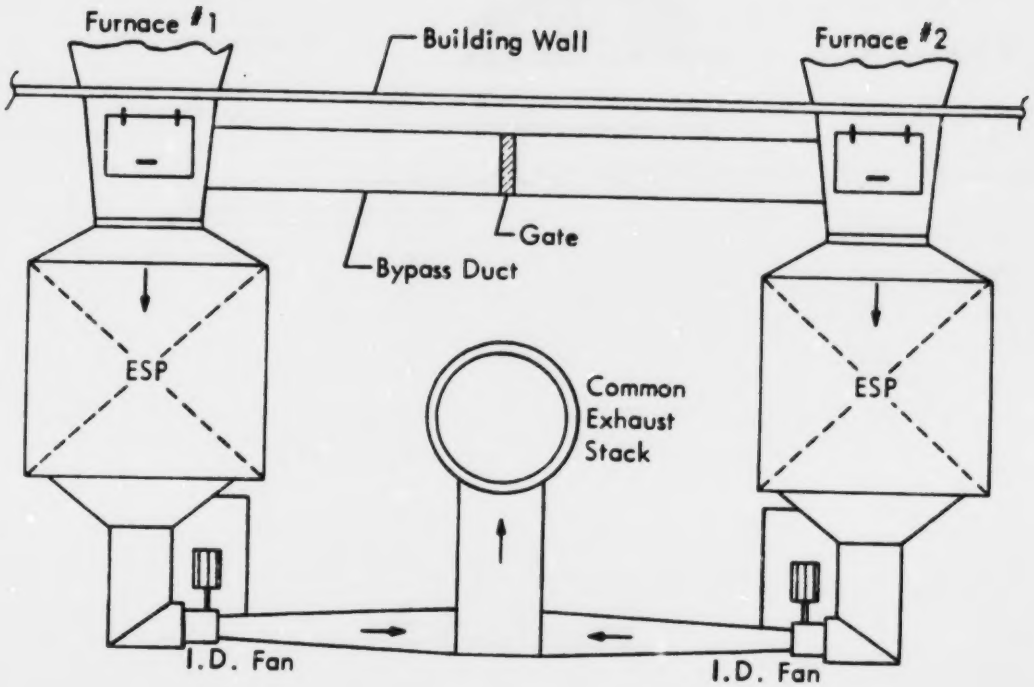

Figure 2-2. Top view of ESP and breeching arrangement.[2]

THE
TOWN OF
BRAINTREE

WASTE DISPOSAL DEPT.
IVORY STREET
BRAINTREE, MASS. 02184

TELEPHONE
843-8209

ONE JOHN FITZGERALD KENNEDY MEMORIAL DRIVE
BRAINTREE, MASSACHUSETTS 02184

October 25, 1978 DUMPING AVERAGES FOR THE FOLLOWING

	CARS	VANS & PICK-UP TRUCKS
Monday	100	84
Tues.	75	76
Wed.	70	68
Thurs.	60	64
Fri.	65	71
Sat.	300	129
Total	670	492

670 cars x 75 lbs.x 4 weeks = 101(tons (monthly
5 weeks = 126 TPM

492 vehicles x 500 lbs.x 4 weeks = 492 (tons monthly)
5 weeks = 615 TPM

Source	Average Tons Per Day	
Residential	57)	
Schools	6)	
Other Depts. & State	2)--------	95 Tons
Cars	5)	
Vans & Pick-Up Trucks	25)	

The amount of refuse generated by the Town of Braintree averages from 95 to 100 tons per day.

Figure 2-3. Solid waste sources for the Braintree municipal incinerator.

Source	Percent
Residential	60.0
Schools	6.3
Other departments and State	2.1
Cars	5.3
Vans and pickup trucks	26.3
	100.0

Refuse charged to the furnace falls first onto an inclined grate, where initial drying of the refuse occurs. The inclined feed grate travels at 2.1 m/h (7 ft/h). The burn grate is a horizontal traveling grate designed for a heat release rate of 3240 MJ/m^2 (285,000 Btu/ft^2) per hour. The burn grate travels at 9.1 m/h (30 ft/h). Underfire air is supplied to the refuse bed by a forced-air fan. Residual ash and noncombustible material are discharged at the end of the grate into a water-filled quench trough. The quenched material is continually removed by a drag chain conveyor and deposited in a dump truck, which transports the ash to a nearby landfill. Quench water is disposed of via the city sanitary sewer system.

The boiler units are of the single-pass design. A waterwall heating surface of 83.1 m^2 (895 ft^2) precedes the boiler tube section on each unit. Additional boiler specifications are listed below:

Manufacturer: Riley Stoker Company

Year built: 1971

Model: Type RX

Rated capacity: 14,000 kg (30,000 lb) of steam per hour

Design pressure: 175,775 kg/m^2 (250 psig)

Design temperature: 208°C (406°F) (saturated)

Furnace volume: 78.7 m^3 (2780 ft^3)

Furnace area: 101.7 m^2 (1095 ft^2)

Waterwall heating surface area: 83.1 m^2 (895 ft^2)

Total heating surface area: 307.0 m^2 (3305 ft^2)

A portion of the steam produced (20 to 30 percent) is sold to nearby industrial users. The remainder is dissipated via two rooftop condensers because no other local market is available for the steam.

Temperatures in the furnace combustion zone are on the order of 1310°C (2400°F), and excess air levels sometimes exceed 400 percent. Flue gas temperatures normally range from 200° to 310°C (400 to 600°F). Exhaust gases from the incinerators are directed into individual ESP's. A bypass duct connecting the inlet sections to the ESP's (see Figure 2-2) allows the exhaust gases from one boiler to be diverted through both precipitators in parallel or to the opposite ESP. Specifications for the precipitators are:

Manufacturer: Wheelabrator-Frye

Number of passages: 12

Number of fields: Single field

Plate-to-plate spacing: 25.4 cm (10 in.)

Plate height: 4.6 m (15 ft)

Plate collecting area: 440 m^2 (4740 ft^2)

Specific collection area (SCA): 6.89 m^2 per 1000 m^3/h (126 ft^2 per 1000 ft^3/m)

Gas velocity: 1 m/s (3.4 ft/s)

Design particulate collection efficiency: 93 percent

After passing through the precipitator, the boiler flue gases enter the induced draft fan and are discharged through a metal stack common to both precipitator units. Exhaust gas flow rates from each of the ESP's are in the range of 420 to 710 std. m^3/min (15,000 to 25,000 scfm). Particulate matter collected by the precipitators is sluiced with water into the incinerator bottom ash quench trough.

SECTION 3

EXPERIMENTAL TEST PLAN

This section describes the test plans for both the fabric filter and venturi scrubber. These plans were developed as a guideline for obtaining target data required for an effective evaluation of each control device. Because of several contributing factors, an abbreviated version of the scrubber test plan was actually executed. These changes are discussed in greater detail in Section 5.

The tasks outlined in the original test plan can be broadly classified into two general objectives:

(1) To determine the physical and chemical character of emissions from this waste-to-energy source and the effectiveness of each control technology in the control of these emissons.

(2) To evaluate the engineering aspects of the use of each control technology in this application, in sufficient detail to provide accurate design of full-scale systems.

The test plans discussed are based on these two objectives.

3.1 EMISSION CHARACTERIZATION

The priority project objective was to characterize the pollutant removal efficiencies of each control device under a set of

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variable operating conditions. It was assumed that any full-scale installation must operate with varying flue gas temperature and fluctuating flue gas compositions that result from variation in waste feed. The experimental plan was to measure and monitor these two factors and perform a test program during "normal" operating conditions.

The following characteristics of the inlet and outlet gas streams from each device were to be measured simultaneously in accordance with EPA reference methods. (See Appendix A for the sampling and analytical methods used.)

- Total particulate concentration
- Chloride and fluoride concentrations
- Sulfur oxide concentrations
- Elemental composition of particulate
- Selected trace metals
- Percent oxygen
- Percent carbon dioxide

Figures 3-1 and 3-2 are schematics of the fabric filter and scrubber operated and tested by PEDCo Environmental personnel. On each device, flue gas samples were taken at the inlet and outlet simultaneously. The fabric filter was operated with a precoat additive (Minuteman, Type S, Hydrated Lime), which was aspirated into the inlet of the fabric filter, but downstream of the inlet sample port. Grab samples of the precoat lime were taken from the lime storage bin.

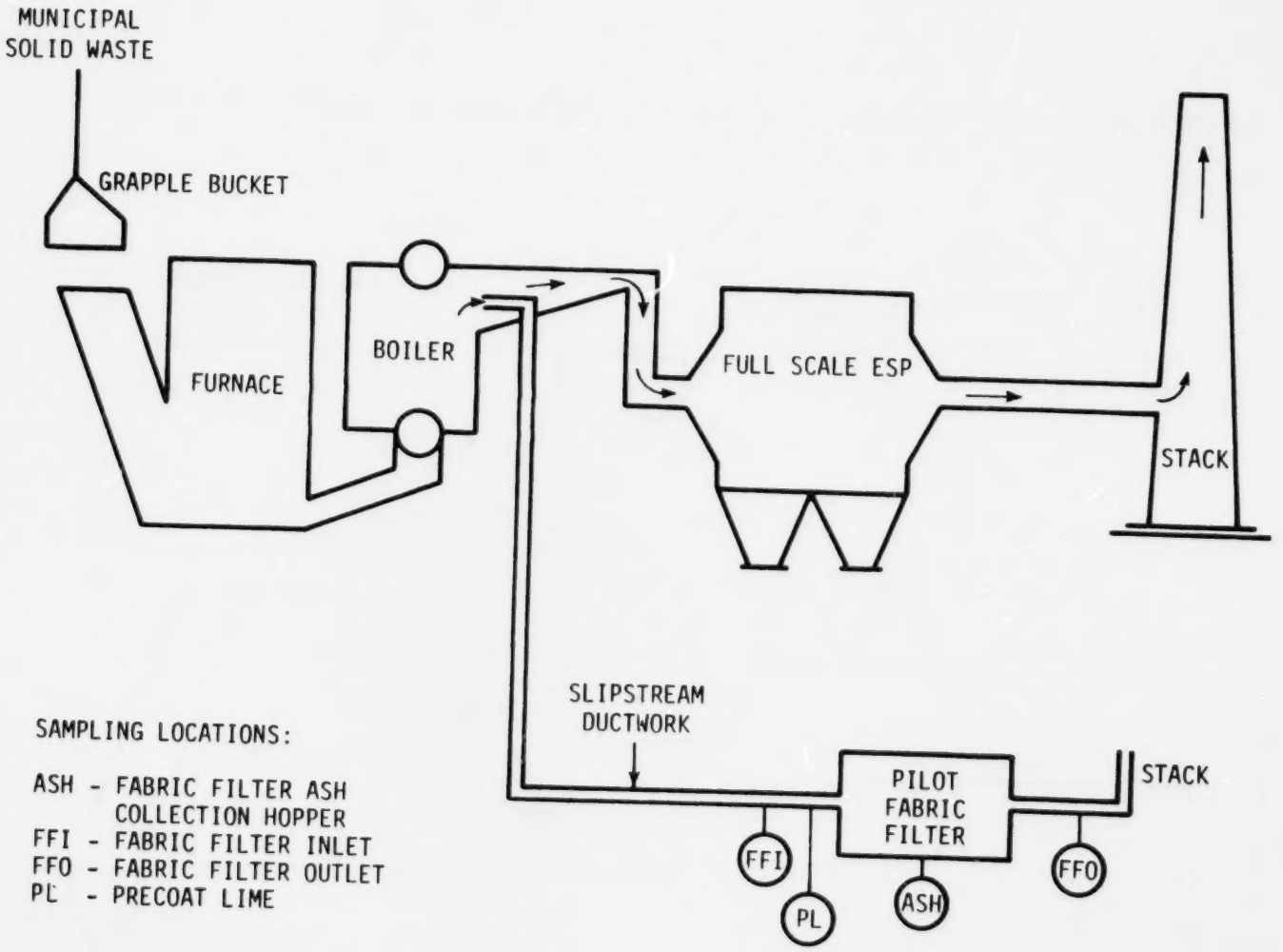

Figure 3-1. Schematic of pilot fabric filter at Braintree, Massachusetts, incinerator.

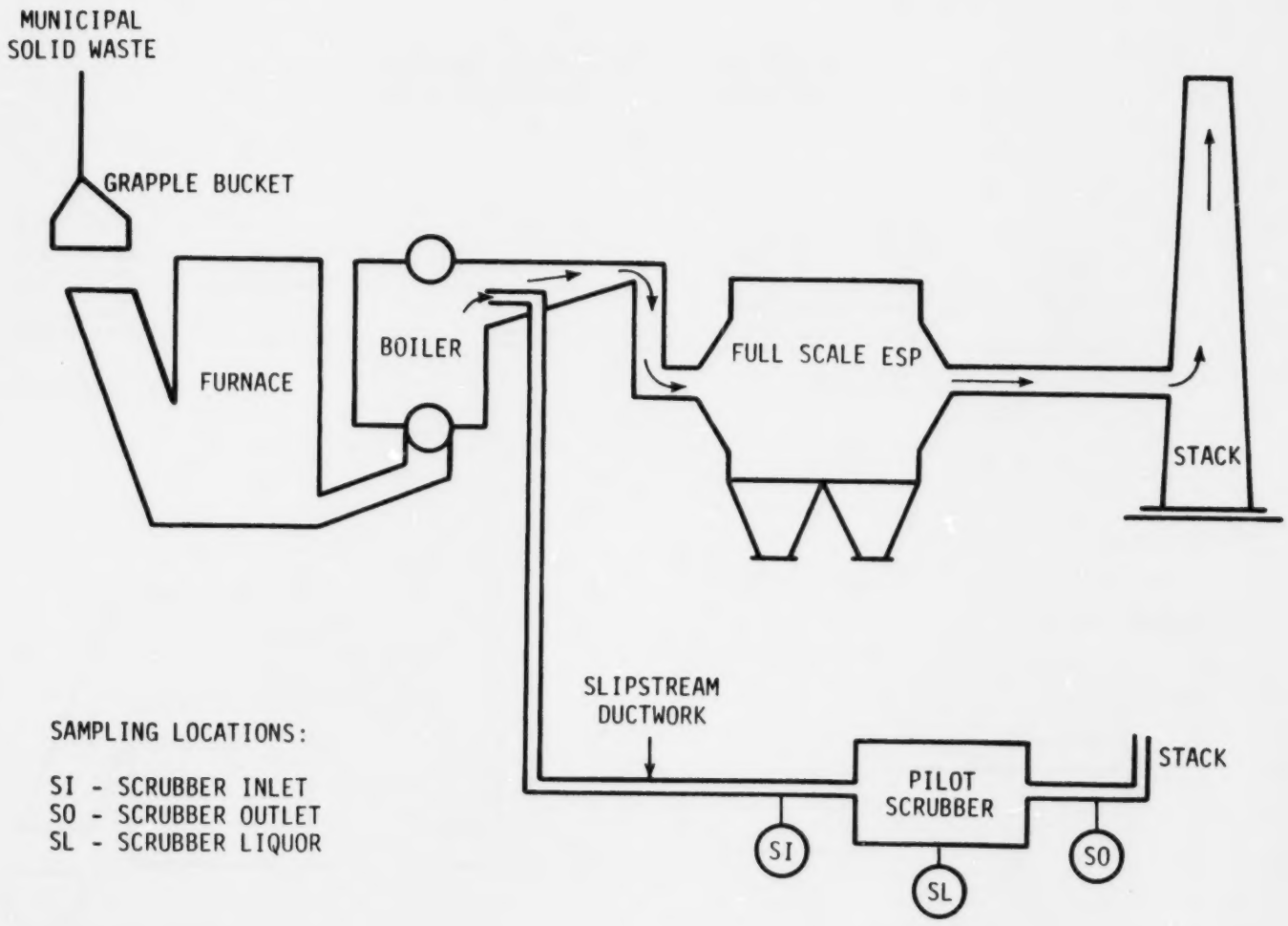

Figure 3-2. Schematic of pilot scrubber at Braintree, Massachusetts, incinerator.

The venturi scrubber was operated with an unfiltered recycling scrubber liquor that was pH-controlled (6-8) with the addition of soda ash ($NaCO_3$). (See Section 4 for more details and discussion of the operation of both control devices.)

Table 3-1 summarizes the Braintree sampling and analytical plan. Tables 3-2 and 3-3, sample matrices for the fabric filter and venturi scrubber, indicate the number of tests for each set of operating conditions.

The sampling program for the evaluation of the pilot fabric filter and scrubber included the following:

- Simultaneous sampling of air emissions at the inlet and outlet of each control device, with a source sampling train (SST).
- Collection of a grab sample of ash from the mobile fabric filter during each sampling run.
- Collection of a grab sample of fabric filter precoat (when used) during each sampling run.
- Collection of a grab sample of unfiltered scrubber liquor during each run. The pH and temperature of the liquor were measured at the time of sampling.

Other field tasks included:

- Continuous operation of the pilot control device.
- Monitoring of boiler operations and conditions.
- Administration of a quality assurance program and internal audit.

The internal quality assurance audit includes splitting and spiking samples and taking control samples at approximately 10 percent frequency. National Bureau of Standards (NBS) fly ash samples were obtained and analyzed along with routine samples.

TABLE 3-1. SAMPLING AND ANALYSIS PROGRAM

Sample	Type of analysis	Sampling method	Sampling frequency	Sampling recovery	Analysis method
Fabric filter precoat	Elemental composition	Grab	Each run	Discrete and composite	SSMS,[a] AA[b]
Fabric filter ash	Elemental composition	Grab	Each run	Discrete and composite	SSMS, AA
Scrubber liquor	Elemental composition	Grab	Each run	Discrete and composite	SSMS, AA
Mobile fabric filter inlet/outlet	Total particulate	Method 5	3/day	Front half SST[c]	Gravimetric
	Hg	Method 101	6	Total catch SST	FAA[d]
	Cl, F	Method 5	3/day	Back half SST	SIE[e]
	Elemental composition	Method 5	3/day	Front half SST	SSMS
	Trace metals	Method 5	3/day	Front half SST	AA
Mobile scrubber inlet/outlet	Total particulate	Method 5	3/day	Front half SST	Gravimetric
	SO_x	Method 5/SO_x	6	Back half SST	Titration
	Hg	Method 101	6	Total catch SST	FAA
	Cl, F	Method 5	3/day	Back half SST	SIE
	Elemental composition	Method 5	3/day	Front half SST	SSMS
	Trace metals	Method 5	3/day 10	Front half SST	AA

[a] Spark source mass spectrometry.

[b] Atomic absorption.

[c] Source sampling train.

[d] Flameless atomic absorption.

[e] Specific ion electrode.

TABLE 3-2. OPERATING MATRIX OF MOBILE FABRIC FILTER TEST PLAN

Pressure drop, cm W.G. (in. W.G.)	Air-to-cloth ratio, m^3/h per m^2 (acfm/ft^2)			
	Without lime precoat		With lime precoat	
	Below 31 (1.7)	31 (1.7) and above	Below 31 (1.7)	31 (1.7) and above
Below 13.0 (5.1)	6 runs-M5/HAL/TE[a] 1 run-M5/SO_x/TE[b]	2 runs-M5/HAL/TE 1 run-M5/SO_x/TE	Not planned	3 runs-M5/HAL/TE 4 runs-M5/SO_x/TE 1 run-Hg[c]
13.0 (5.1) and above	Not planned	2 runs-M5/HAL/TE	1 run-M5/HAL/TE	4 runs-M5/HAL/TE 2 runs-Hg

[a] M5/HAL: EPA Method 5, back half analyzed for chlorides and fluorides, front half analyzed for particulate and trace elements.

[b] M5/SO_x: EPA Method 5, back half analyzed for sulfur oxides, front half analyzed for particulate and trace elements.

[c] Hg: Mercury analysis only.

TABLE 3-3. OPERATING MATRIX OF PILOT SCRUBBER TEST PLAN

Pressure drop, cm W.G. (in. W.G.)	Liquid-to-gas ratio, liters/1000 m^3 (gal/1000 ft^3)	
	<1610 (<12)	≥1610 (≥12)
25.5 (10.0)	3 runs-M5/HAL/TE[a] 3 runs-M5/SO_x/TE[b]	1 run-M5/SO_x/TE
50.8 (20.0)	1 run-M5/HAL/TE 2 runs-M5/SO_x/TE	2 runs-M5/HAL/TE 1 run-M5/SO_x/TE 3 runs-Hg[c]
76.2 (30.0)	3 runs-M5/HAL/TE 3 runs-M5/SO_x/TE	3 runs-M5/HAL/TE

[a] M5/HAL/TE: EPA Method 5, back half analyzed for chlorides and fluorides, front half analyzed for particulate and trace elements.

[b] M5/SO_x/TE: EPA Method 5, back half analyzed for SO_x, front half analyzed for particulate and trace elements.

[c] Hg: Mercury analysis only.

SECTION 4

PILOT EQUIPMENT DESCRIPTION

Two devices were tested at the Braintree incinerator. The pilot fabric filter that was used in the Ames test program was transported to Braintree for similar testing. A pilot venturi scrubber was rented from the Neptune AirPol Company in Englewood, New Jersey, to evaluate a second control device at this mass-burn incinerator.

4.1 PILOT FABRIC FILTER

PEDCo Environmental, Inc., prepared technical specifications for the pilot fabric filter and subcontracted its design and fabrication. The technical requirements outlined in the specification before initial startup and operation were as follows.

- Must be capable of continuous uninterrupted operation.
- All carbon steel interior surfaces must have high-temperature, corrosion-resistant coating.
- Must have capacity of 85 m^3/min (3000 acfm) at 204°C (400°F).
- Must contain three compartments.
- Must have air-to-cloth of 0.46 m^3/min per m^2 (1.5 ft^3/min per ft^2) (all compartments).
- Must have air-to-cloth of 0.91 m^3/min per m^2 (3.0 ft^3/min per ft^2) (one compartment cleaning, excluding reverse-air flow).

- Must be able to withstand temperature excursions up to 260°C (500°F).
- Leakage of air into the unit must be less than 1.4 std. m^3/min (50 scfm).
- Heat loss across the unit must be minimal.
  - 7.6 cm (3 in.) fiberglass insulation with cover plates.
  - Hopper heaters to maintain 107°C (225°F) with ambient air to -18°C (0°F) and no heat addition from flue gas.

After startup and shakedown of the unit, the leakage and hopper heater capabilities were found to be out of the desired range. A review of inlet/outlet flow rate measurement data confirmed leakage in excess of 1.4 std. m^3/min (50 scfm). All possible attempts were made to hold inleakage to a minimum throughout the subsequent test programs.

The hopper heaters were not capable of maintaining the minimum temperature requirement; nevertheless, they were used whenever possible to avoid acid condensation within the unit.

Other specific design features included:

- A 240-/480-V power supply required. Transformer rewiring possible to accommodate either.
- Control panel and working areas located in one separate 6.6-m (20-ft) trailer.
- Thermocouples and instrumentation for high and low temperature cutoff.
- Automatic flow control and recording system with flow rectifier.
- Opacity monitor and recorder at device outlet.
- Variable reverse air/mechanical shake cleaning mechanism.

- Pressure drop transmitter and recorder.
- Variable cleaning cycle initiation sequence.
- Variable cleaning frequency and dwell times.

With the exception of the differential pressure transmitter, all instrumentation was operable throughout the program. Problems with proper calibration were encountered from startup and were never resolved, although numerous attempts were made to rectify them. All the pressure differential data reported were obtained by manually reading a slack-tube manometer with static pressure taps attached to the inlet and outlet manifolds of the fabric filter.

Figures 4-1 through 4-3 show the Operator's Log (pages 1 and 2), Maintenance Checklist, and Opacity Meter Calibration Checklist that were used to record the operating condition of the fabric filter system during the test program.

A number of operating conditions were measured and recorded automatically. A multipoint recorder received input from several thermocouples and from the flow measuring device located just upstream of the outlet sample point. Figure 4-4 shows a typical multipoint strip chart record. This particular testing period (which is actually from a previous test program) included a reverse-air/mechanical shake cleaning cycle. The record shows a corresponding drop in temperature at the fabric filter interior and at the stack. The drop in flow rate is due to increased

PAGE 1

OPERATOR NAME _____

MAIN GAS FLOW SYSTEM

INITIAL

DATE _____ TIME _____

FAN STATUS _____

OVERRIDE ON ____ OFF ____

HOPPER HEATERS ON ____ OFF ____

FLOW PROBE PURGE

LOW AIR PRESSURE _____

ΔP _____

FLOW _____

OPACITY _____ %

RECORDER CHECK _____

TEMPERATURE °F

	READOUT	RECORDER	#TC	LOCATION
1				
2				
3				
4				
5				
6				
7				
8				

OPERATIONS

#	TIME	COMMENTS
1		
2		
3		
4		
5		
6		
7		
8		
9		

Figure 4-1. Operator's log for fabric filter test program.

PAGE 2

OPERATOR NAME _____

CLEANING CYCLE SYSTEM

INITIAL

DATE _____ TIME _____ ΔP HIGH _____

CYCLES _____ HRS RUNNING ____

CLEANING MODE R S R&S

SIM ____ SEQ ____

CYCLE INITIATED BY OFF ____ TIME ____ PRESS _____

CLEANING TIMES (MIN) FREQUENCY _____

DWELL _____

CLEANING _____

PRESSURE ACTUATOR SET (%) _____ x 20 = _____ IN WATER

	REVERSE AIR FAN	SHAKER MOTORS			OUTLET DAMPERS			REVERSE AIR INLET DAMPERS		
		1	2	3	1	2	3	1	2	3
OFF										
MANUAL										
AUTOMATIC										

OPERATIONS

#	TIME	COMMENTS
1		
2		
3		
4		
5		
6		
7		
8		
9		

Figure 4-1 (continued)

MAINTENANCE CHECKLIST

DATE OPERATOR NAME _____

MAIN FAN
TIME _____
COMMENTS

OPERATING _____
LUBRICATION _____

BEARINGS CHECK _____
DATE SCHEDULED _____

REVERSE AIR FAN
TIME _____
COMMENTS

OPERATING _____
LUBRICATION _____

BEARINGS CHECK _____
DATE SCHEDULED _____

SHAKERS
TIME _____
COMMENTS

MOTORS OPERATING #1 _____ #2 _____ #3 _____
ASSEMBLIES OPERATING #1 /// #2 /// #3 ///
BEARINGS CHECK #1 _____ #2 _____ #3 _____

DAMPERS
TIME _____
COMMENTS

REVERSE AIR #1 _____ #2 _____ #3 _____
OUTLET #1 _____ #2 _____ #3 _____

SCREW CONVEYOR ASH COLLECTION
TIME _____

SCREW MECHANISIM & MOTOR _____
COMMENTS

	TIME			WEIGHT		
DRUM #	INITIAL	FINAL	NET	GROSS	TARE	NET

Figure 4-2. Maintenance checklist for fabric filter test program.

INSTRUMENT CALIBRATION DATA

OPACITY METER

DATE INITIAL TIME FINAL TIME

OPACITY %	INITIAL READING	FINAL READING
ZERO		
191		
600		
877		
100		

COMMENTS

Figure 4-3. Opacity meter calibration checklist for fabric filter test program.

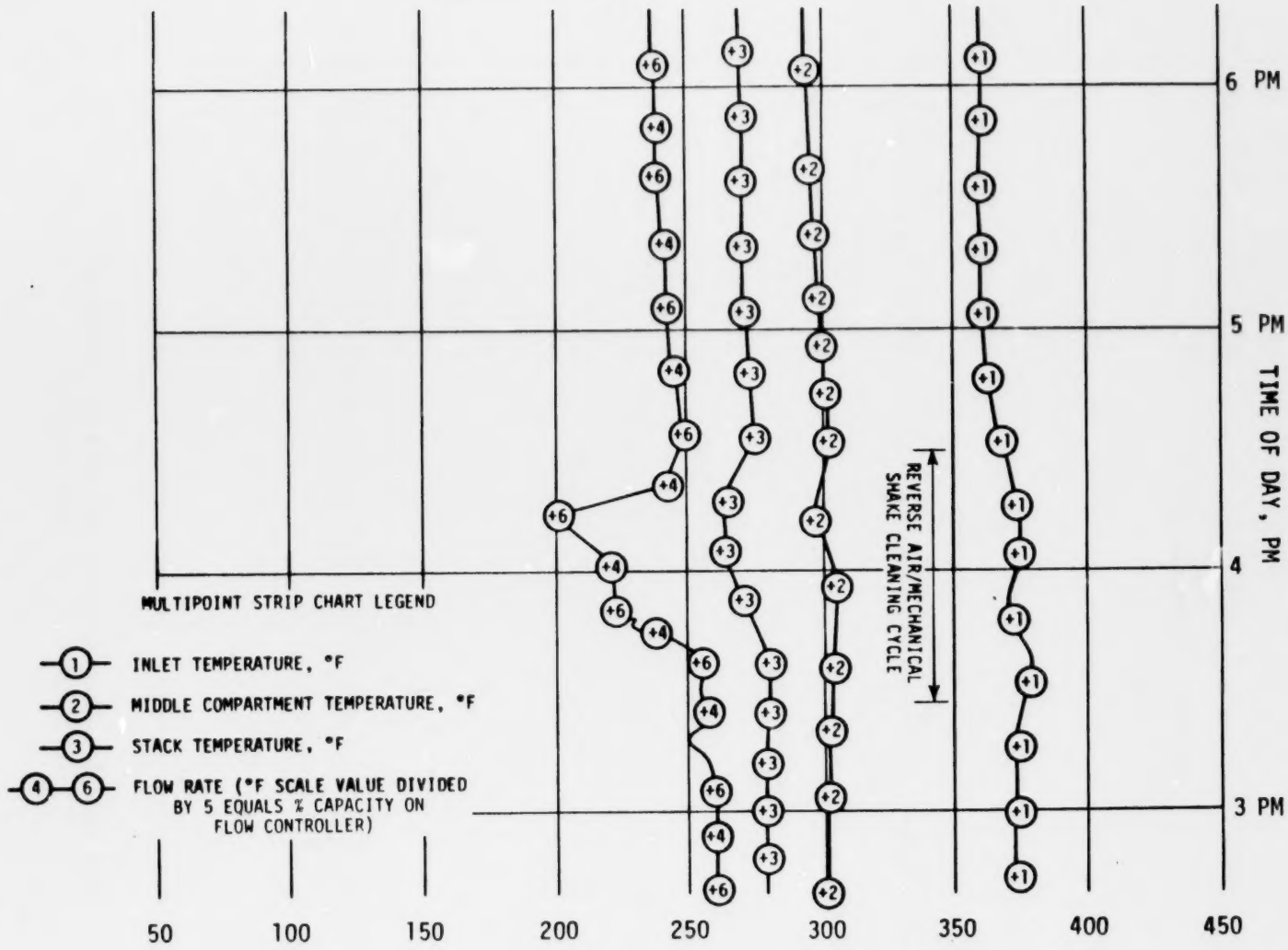

Figure 4-4. Pilot fabric filter multipoint strip chart - July 13, 1979.

pressure drop from two-compartment operation without a proportional decrease in flow rate. The flow rate decreases automatically when the capacity limit of the upper fan is reached at the increased pressure loss.

A lime precoat was aspirated directly into the flue gas at the inlet to the fabric filter. The lime was Minuteman (brand) Type S hydrated lime. Initially, 150 lb of precoat was added, and subsequently, 50 lb a day for the rest of the test period. The purpose of the precoat was to control those gaseous pollutants not normally removed by a fabric filter.

Opacity of the stack gas was also measured optically and recorded. Figure 4-5 is an example of a strip chart of opacity readings; it corresponds to the multipoint strip chart shown in Figure 4-4.

4.2 PILOT SCRUBBER

The pilot scrubber used in this program was rented from Neptune AirPol, who designed and fabricated the unit. Figure 4-6 is a schematic of the device.

Scrubber liquor was injected into the venturi section at three points--two tangential nozzles upstream of the throat and one at the venturi throat. Flowmeters were placed in the system so they could monitor total liquor flow rate and the distribution of the flow between the three injection points. At full liquid and gas-flow conditions, total flow rate of the liquor through

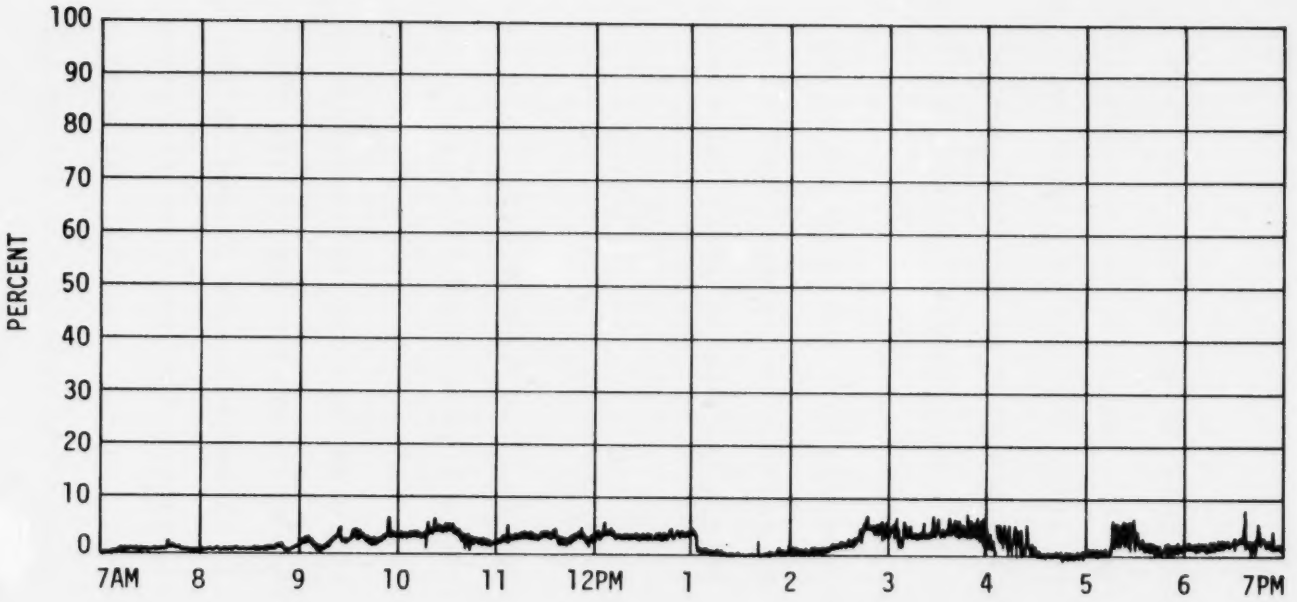

Figure 4-5. Pilot fabric filter opacity strip chart - July 13, 1979.

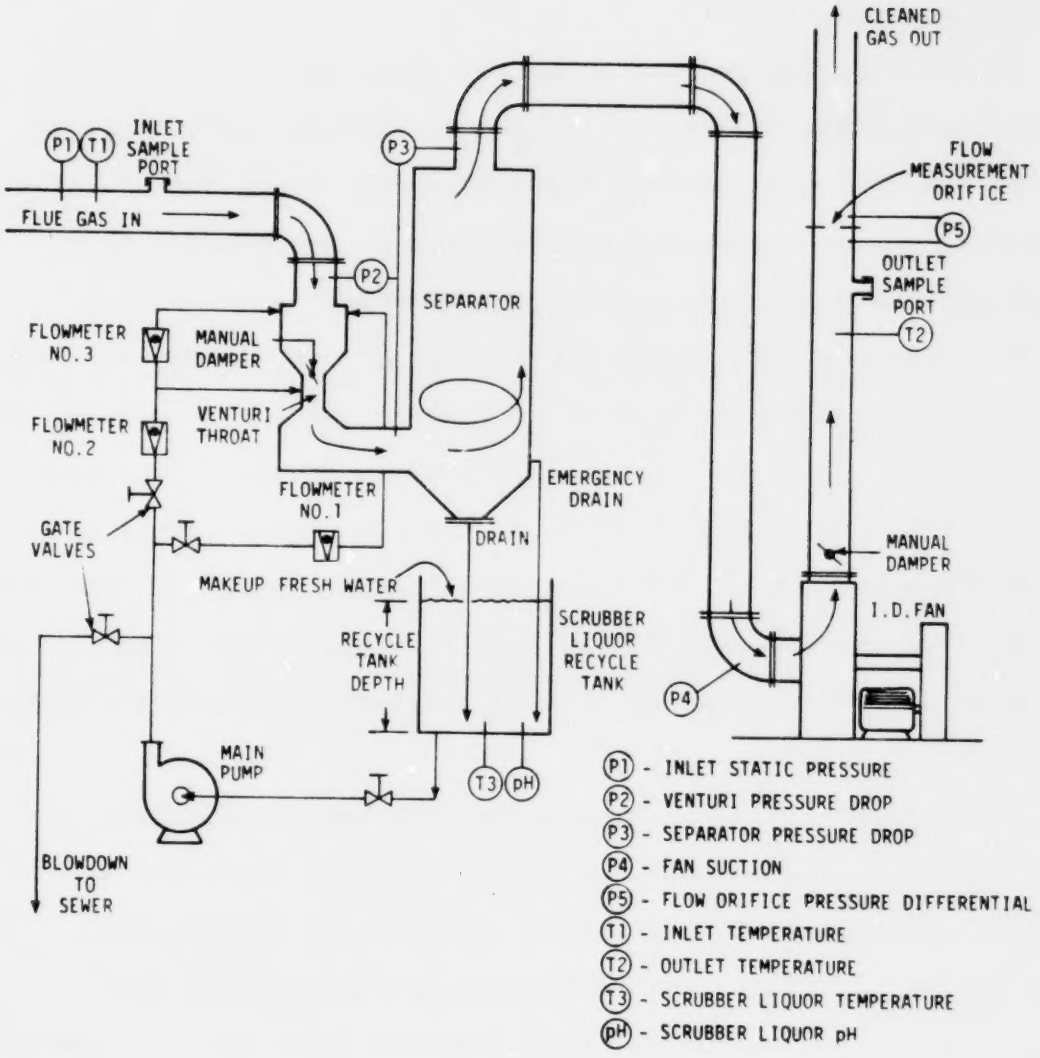

Figure 4-6. Schematic of the pilot scrubber used at Braintree.

both tangential nozzles was 85 percent of the total flow leaving the pump. The remainder (15%) of the liquor entered the venturi through the throat nozzle.

The acidity (pH) of the scrubber liquor was controlled by periodic additions of soda ash (Na_2CO_3). The pH was allowed to drop to 6 before soda ash was added to raise the pH back up to 8. The pH was measured every 15 minutes with pH color-coded test strips and every hour, by a portable pH meter.

The pressure drop across the venturi (P_2 in Figure 4-6) was manually adjusted to the desired setting by opening or closing the damper at the top of the throat. The actual pressure drop used for each test run is discussed in Section 5. The pressure drop across the separator (P_3 in Figure 4-6) generally ranged from 0.5 cm W.G. (0.2 in. W.G.) to 3.8 cm W.G. (1.5 in. W.G.). This parameter is not adjustable; it is a function of scrubber liquor flow rate and gas flow rate.

The flow measurement orifice was utilized to maintain constant gas flow rate through the scrubber during testing. The orifice was calibrated by relating the pressure differential readings (P_3 in Figure 4-6) to preliminary source test data obtained through EPA Method 2. This pressure differential reading was set at a corresponding flow rate of 0.94 m/s (2000 acfm) at the scrubber inlet during all test runs. In this manner, liquid to gas (L/G) could be controlled by adjusting the total scrubber liquor flow rate. The L/G value reported in the operating conditions log was calculated from the flow rate data from each source test (Method 5) and the corresponding scrubber liquor flow rate.

SECTION 5

PRESENTATION OF RESULTS

The test data and analytical results presented in this section are organized into three separate parts: subsection 5.1 briefly summarizes plant operating conditions during the time of testing, subsection 5.2 presents results of sampling and analysis performed during the pilot fabric filter test, and subsection 5.3 presents results of sampling and analysis performed during the pilot scrubber test. This section is supplemented by Appendix A, which describes the sampling and analytical methods used.

5.1 INCINERATOR OPERATING CONDITIONS

Incinerator operating conditions were summarized and presented as average normal conditions throughout the test periods. Attention was given to maintaining the "steady-state" of normal conditions throughout testing. Pertinent operating data were recorded at 15-minute intervals during each test run. Because these data are voluminous, only the average normal operating conditions are reported. Plant operations were generally consistent throughout the entire test program. Only the feed characteristics (i.e., fuel quality) of the refuse to the furnace varied significantly. No attempt was made to characterize the waste on an individual test run basis. The average characterization of the waste is reported in Section 3.

Table 5-1 presents incinerator operating conditions monitored during the fabric filter tests and those monitored during the scrubber tests. The two averages vary only slightly even though these data represent a compilation of readings taken every 15 minutes over a 2-month period.

5.2 PILOT FABRIC FILTER

The pilot fabric filter was operated at the Braintree site August 28 through September 14, 1979, and was tested on 27 runs. Table 5-2 shows the operating conditions of the fabric filter. The air-to-cloth (A/C) ratio is from the fabric filter log sheets (Figure 4-2). The flow rate recorded on the log sheet was measured by a probe in the outlet duct of the fabric filter.

An evaluation of the particulate removal efficiencies and outlet grain loadings for each test run reveals two distinct groups, termed "first-half" and "second-half." Table 5-3 shows the average particulate removal efficiencies, including an overall average. The first-half group includes Test Runs 101 through 112, which took place on or before August 30, 1979. The second-half group include Test Runs 113 through 127, which took place during September 1979.

Average particulate removal efficiencies vary greatly between the two groups. The first-half tests are not included in further data reduction because operational problems in the fabric filter (corrected during the first week of September) prevented collection of "representative" operation data during the first half of the test program.

TABLE 5-1. AVERAGE INCINERATOR OPERATING CONDITIONS

		Fabric filter[a]	Scrubber[b]
Grate speed setting	Feed stoker, m/h	2.1	2.1
	Burn stoker, m/h	9.1	9.1
Furnace draft	Fan speed, rpm	554	530
	cm W.G.	.05	.05
Precip. draft outlet	cm W.G.	4.6	2.8
Underfire forced draft	Stoker box pressure, cm W.G.	2.5	2.5
	Fan speed, % L or H[c]	50 L	50 L
Overfire air	cm W.G.	0	0
Temperature	Furnace, °C	830	780
	Furnace outlet gas, °C	220	220
Steam header pressure, cm W.G.		1.4×10^4	1.4×10^4
Cond. pressure range, cm W.G.	No. 1	$0\text{-}1.2 \times 10^4$	$0\text{-}1.4 \times 10^4$
	No. 2	$0\text{-}1.1 \times 10^4$	$0\text{-}1.5 \times 10^4$
Steam flow, 1000 kg/h		5.4	16.2
Excess O_2, % at furnace outlet		12.6	11.4

[a] Average conditions over fabric filter test program.

[b] Average conditions over scrubber test program.

[c] L = low; H = high.

TABLE 5-2. FABRIC FILTER OPERATING CONDITIONS

Test Run	Date	Time	A/C ratio, m^3/h per m^2	ΔP, cm W.G.
101-F	8/28	0230-0330	36.6	13.5
102-F	8/28	0425-0525	36.6	14.2
103-F	8/29	0030-0141	32.9	11.9
104-F	8/29	0240-0342	27.4	11.9
105-F	8/30	0040-0140	32.9	12.2
106-F	8/30	0220-0320	31.1	11.2
107-F	8/30	0554-0664	27.4	10.2
108-F	8/30	0815-0915	20.1	10.2
109-F	8/30	0940-1040	20.1	11.4
110-F	8/30	1110-1210	20.1	11.4
111-F	8/30	1245-1335	23.8	12.7
112-F	8/30	1400-1500	22.0	12.7
113-F	9/11	0920-1020	34.8	9.9
114-F	9/11	1235-1335	31.1	10.7
115-F	9/11	1455-1555	31.1	13.7
116-F	9/12	0940-1040	34.8	15.0
117-F	9/12	1215-1315	27.4	18.0
118-F	9/12	1500-1600	36.6	10.2
119-F	9/12	1630-1720	31.1	9.1
120-F	9/13	0830-0930	31.1	8.9
121-F	9/13	1015-1115	31.1	11.2
122-F	9/13	1210-1310	31.1	12.9
123-F	9/13	1410-1510	31.1	13.7
124-F	9/13	1615-1715	32.9	15.8
125-F	9/14	0845-0945	36.6	12.2
126-F	9/14	1015-1115	36.6	13.5
127-F	9/14	1210-1310	36.6	13.7

To convert from	to	multiply by
m^3/h per m^2	ft^3/h per ft^2	5.47 E-2
cm W.G.	in. W.G.	3.94 E-1

TABLE 5-3. PARTICULATE REMOVAL EFFICIENCY AS A FUNCTION OF TEST GROUP

Test group	Average efficiency, %	Standard deviation
All tests (27 tests)	88.8	9.0
Tests 101-112 (first-half)	82.9	8.1
Tests 113-127 (second-half) (excluding 18, 25, 26, 27)[a]	95.1	4.5

[a]Except for Run 18, these were not particulate sample runs, and Run 18 did not meet quality assurance criteria.

The operational problem in the fabric filter was due primarily to improper seals around several bag connections at the tube sheet (the floor of the unit). The unit was inspected, leaks were isolated, and bag connections were resealed. The problem was first encountered during the Ames program earlier in the year and was believed to have been corrected.

Because of the large difference in first-half and second-half particulate removal results and the high confidence level associated with second-half results, the entire first-half test group is considered invalid and is not discussed further.

Table 5-4 lists emission concentrations that were calculated from sampling and analytical results obtained with the pilot fabric filter. Test runs are grouped according to similar operating conditions. The results from test runs within each group are averaged; however, each emission concentration shown may not be an average of all the test runs in the group. In some instances an individual sample may not have been analyzed for a specific pollutant, but it is included in the operational group to be averaged for other emission concentrations.

Emission concentrations can be graphically related to a number of variable conditions in an attempt to recognize trends that may indicate specific conditions which lower emissions of potentially harmful pollutants. Figure 5-1 shows particulate removal efficiency as a function of pressure drop with respective A/C ratio. At a specific A/C ratio (high or low), particulate removal efficiency increased with increased pressure drop; however,

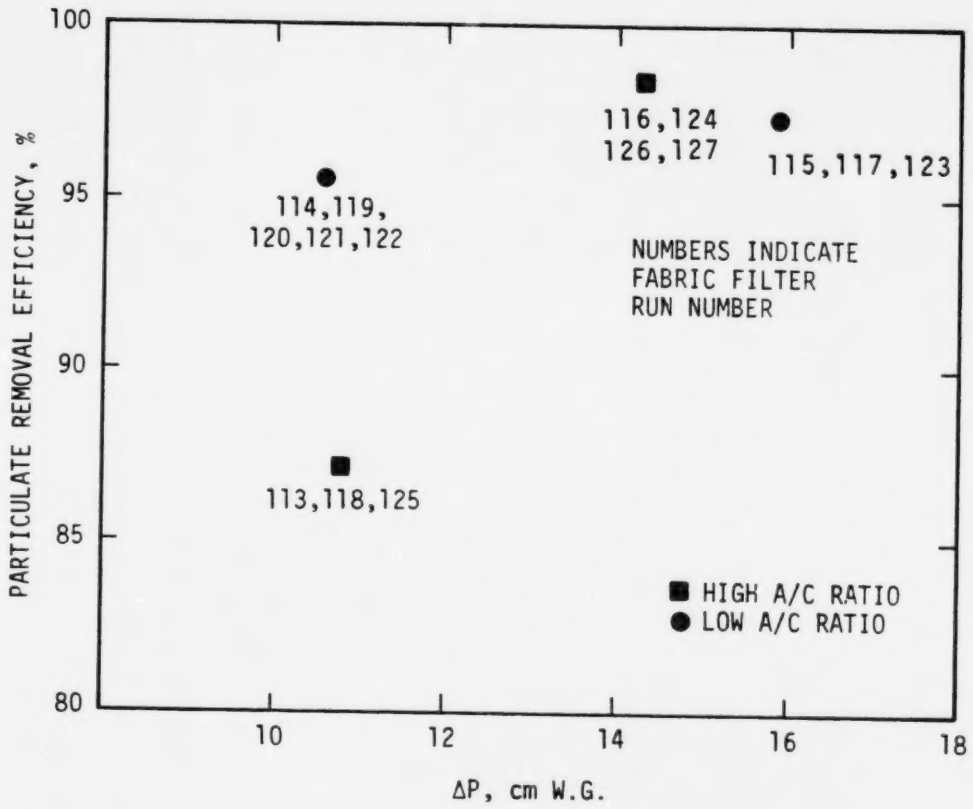

Figure 5-1. Fabric filter - particulate removal efficiency as a function of A/C ratio and pressure drop.

TABLE 5-4. FABRIC FILTER EMISSIONS CONCENTRATION

OPERATING CONDITIONS (units as noted)				
ΔP (cm W.G.)	10.6	10.8	14.5	15.1
A/C (m^3/h per m^2)	31.1	36.0	35.2	29.9
Run No.	114,119,120,121, 122	113,118,125	116,124 126,127	115,117,123
ANALYTICAL RESULTS (mg/dscm)				
Gravimetric Analysis				
Particulate (in)[a]	546.1 (150-760)[b]	657.5	640.0 (490-790)	540.8 (450-700)
(out)	24.55 (4-56)	84.34	15.14 (12-18)	9.80 (4-16)
Specific Ion Electrode				
Cl (in)	437 (260-610)	338	314 (240-390)	302 (270-360)
(out)	206 (69-342)	241	201	226 (210-240)
Atomic Absorption Analysis				
Pb (in)[c]	8.79 (3-20)	8.56	7.61 (7-8)	4.96 (4-6)
(out)	0.0147 (ND[d]-0.02)	ND	0.0132 (0.012-0.014)	0.024 (ND-0.035)
Cd (in)[e]	0.383 (0.2-0.5)	0.411	0.229 (0.19-0.27)	0.214 (0.17-0.26)
(out)	0.00356 (ND-0.004)	ND	ND	ND
Fe (in)	1.7 (0.8-2.5)	0.827	0.909 (0.70-1.28)	0.442 (0.34-0.54)
(out)	0.024 (0.014-0.034)	0.047	0.028 (0.014-0.043)	0.054 (0.04-0.07)
Cu (in)[f]	0.258 (0.2-0.3)	0.350	0.284 (0.22-0.34)	0.170 (0.14-0.21)
(out)	0.0110 (ND-0.02)	ND	6.48 x 10^{-4} (7.4-9.5 x 10^{-4})	5.29 x 10^{-4} (ND-5.29 x 10^{-4})
Zn (in)	18.4 (2-30)	19.6	14.7 (11-19)	7.874 (6-9)
(out)	0.0581 (0.03-0.09)	0.00703	0.046 (0.03-0.06)	0.023 (0.011-0.029)
Hg (in)		0.591	0.776 (0.5-1.0)	
(out)		0.146	0.217 (0.1-0.3)	
Ba $(ClO_4)_2$ Titration				
SO_x (in)	308	228		
(out)	189	149		

[a] Front half only.

[b] All emission concentrations within the parentheses express the nominal range of emissions. Where ranges are not shown, only one run was reported. Ranges have been rounded and thus cannot be used statistically. They are provided to give the reader an idea of the orders of magnitude observed in the results.

[c] Detection limit for Pb is 0.007 mg/dry std. m^3.

[d] Not detectable.

[e] Detection limit for Cd is 0.002 mg/dry std. m^3.

[f] Detection limit for Cu is 0.0003 mg/dry std. m^3.

the A/C ratio does not seem to affect the particulate removal capabilities of the fabric filter within the A/C ranges that were tested.

Figure 5-2 shows outlet particulate concentration as a function of pressure drop with respective A/C ratio. Again, increased pressure drop improved operation of the filter; however, no correlation was apparent between A/C and outlet particulate concentration.

The control of heavy metal emissions by the fabric filter was highly effective. Inlet lead concentrations ranged from 3 to 20 mg/dry std. m^3, and the average removal efficiency for valid test runs was greater than 99.5 percent.

Uncontrolled cadmium emissions were about one-twentieth of the amount of lead concentration and they were controlled effectively by the fabric filter (greater than 99 percent). Only two outlet samples contained cadmium that could be detected. Controlled emissions during these two runs showed an average of 0.00356 mg/dry std. m^3.

Iron emissions measured at the inlet and outlet did not appear to follow a significant trend; however, the removal efficiencies (88 to 99 percent, as calculated from the averages on Table 5-4) were not as high as expected. This could have been caused by several things, including the long-term effect of corrosion within the fabric filter.

Controlled copper emissions decreased with increased pressure drop (see Table 5-4). The lowest average outlet copper concentration occurred at the highest pressure drop tested.

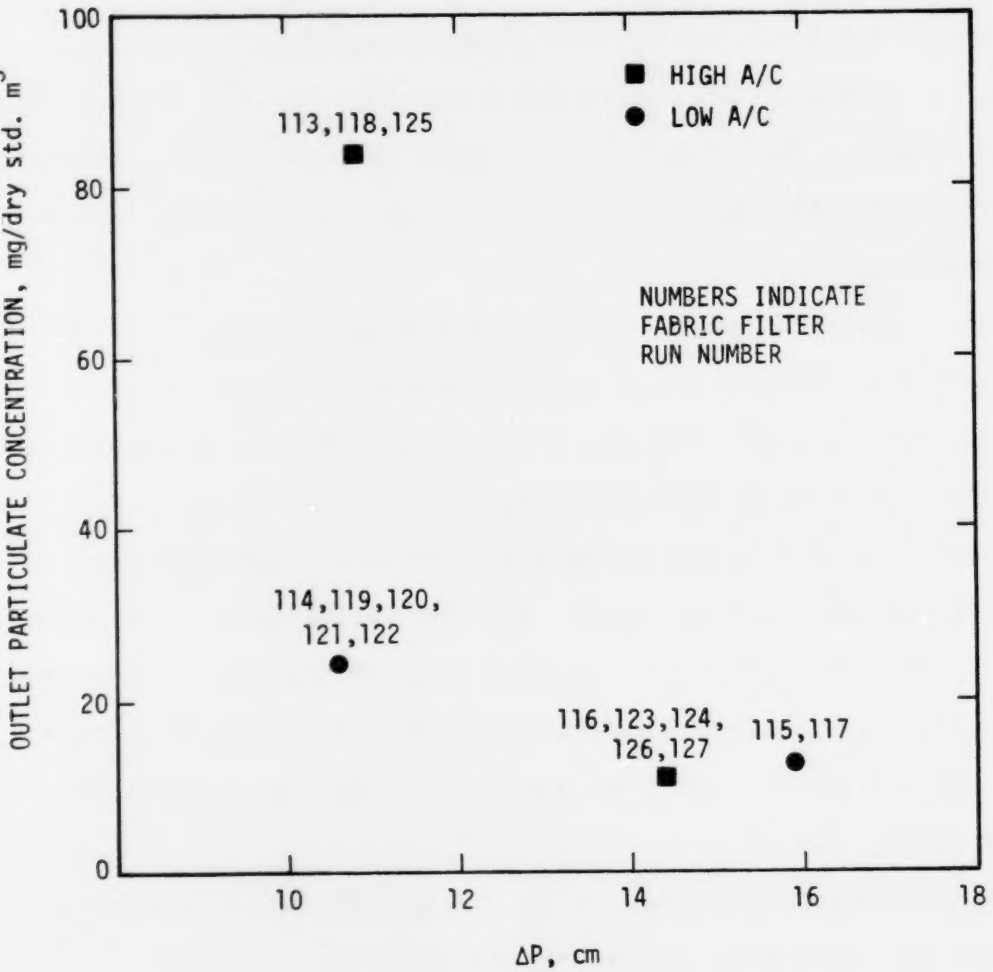

Figure 5-2. Fabric filter - outlet particulate concentration as a function of pressure drop.

Removal efficiencies calculated from the average concentrations also improve with increased pressure drop (95.7 to 99.7 percent).

Uncontrolled zinc emissions exhibited the highest concentrations when compared to the other metals analyzed; however, they were controlled effectively. The average collection efficiency for zinc emissions was greater than 99 percent in every case.

Fabric filter operating conditions seemingly do not affect controlled mercury emissions. Removal of mercury by the precoated fabric filter was in the 70 to 75 percent range.

The control of chlorides through the use of a lime precoat was not as effective as expected. Chloride removal efficiency with lime precoat averaged 28 percent. Figure 5-3 shows chloride removal efficiency as a function of pressure drop. Increasing the pressure drop had no apparent effect on chloride removal.

The effect of precoat was evaluated in the control of SO_x emissions. The removal efficiency for SO_x at the Braintree incinerator averaged 37 percent with the lime precoat. At Ames, where the fabric filter was tested without precoat, SO_x removal efficiency averaged about 20 percent. The uncontrolled SO_x concentrations at Ames, however, were almost 100 times greater than those at Braintree (18,000 mg/dry std. m^3 versus 270 mg/dscm). Thus, it appears that lime precoating has a significant effect on some gaseous pollutants.

5.3 PILOT SCRUBBER

The venturi scrubber was installed and operated at the Braintree incinerator from October 2 to October 12, 1979.

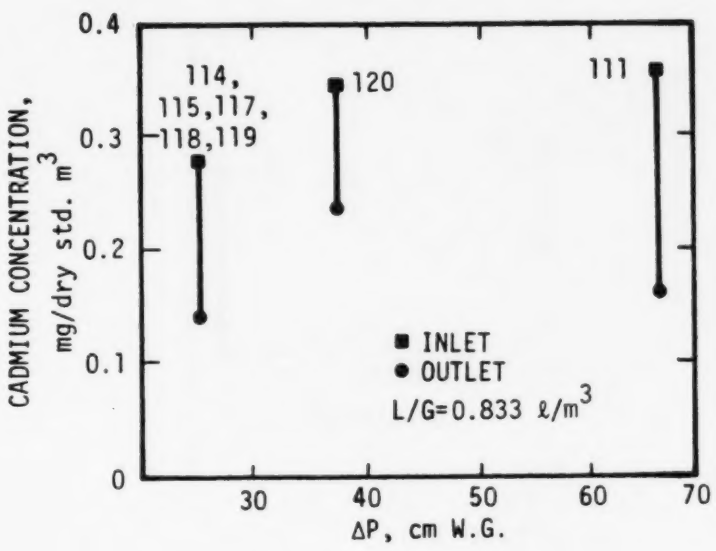

Figure 5-11a. Cadmium concentration vs. pressure drop (low L/G).

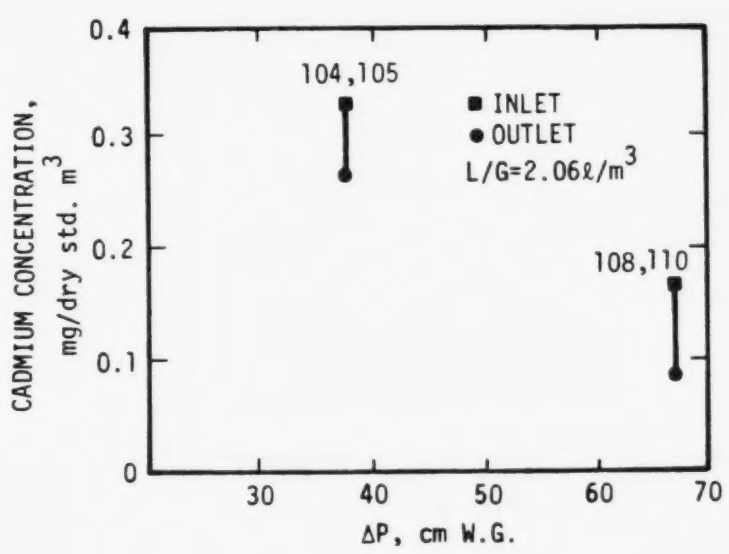

Figure 5-11b. Cadmium concentration vs. pressure drop (high L/G).

Note: Numbers within each graph indicate scrubber run number.

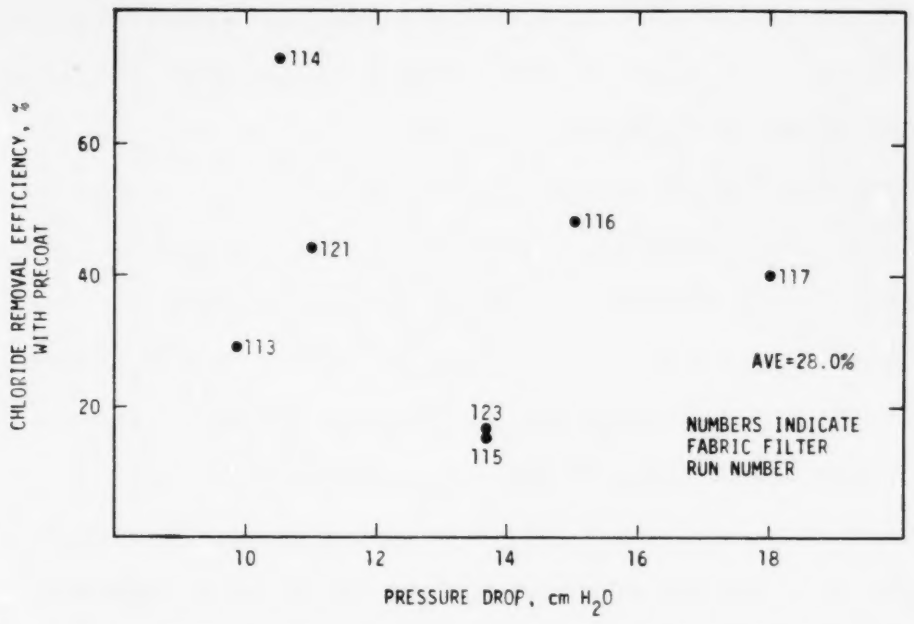

Figure 5-3. Fabric filter with precoat - chloride removal efficiency as a function of pressure drop.

A total of 25 test runs were performed. Table 5-5 lists the tests and the scrubber operating conditions that were maintained during each test. The two variable scrubber parameters were liquid-to-gas ratio (L/G) and pressure drop across the venturi throat (ΔP). The L/G ranged from 0.789 liter/m^3 (5.9 gal/1000 ft^3) to 2.46 liters/m^3 (18.4 gal/1000 ft^3). The pressure drop ranged from 25.4 cm W.G. (10 in. W.G.) to 81.3 cm W.G. (32 in. W.G.).

The L/G was determined by measuring the volumetric flow rate of the flue gas by EPA Method 2 and adjusting the scrubber liquor flow rate to give the desired L/G.

The pressure drop across the venturi throat, which was varied by manually opening and closing the throat, was adjusted to the desired ΔP for each test.

Table 5-6 presents scrubber emissions concentrations. Test results were grouped, and emission concentrations were averaged for those runs in which test conditions were similar. For example, Test Runs 114, 115, 117, 118, and 119 were performed while the scrubber was operating with an L/G averaging 0.833 liter/m^3 (6.2 gal/1000 ft^3) and a ΔP of 25.4 cm (10 in.) W.G. Inlet and outlet average emission concentrations were reported for each pollutant investigated. All particulate data represent the average of all the runs indicated for that group; however, other emission concentrations do not necessarily represent averages of all test runs. Samples were selected for analysis, and not all pollutants were determined in each sample. The nominal ranges

TABLE 5-5. SCRUBBER OPERATING CONDITIONS

Test Run	Date	Time	L/G, liters/m^3	ΔP, cm W.G.
101-S	10/2	1650-1750	1.660	41.9
102-S	10/2	1840-1940	1.820	40.6
103-S	10/2	2030-2130	2.060	40.6
104-S	10/3	1840-1940	1.850	31.8
105-S	10/3	2020-2110	1.940	33.8
106-S	10/4	1615-1715	2.250	33.0
107-S	10/4	1755-1855	1.950	26.2
108-S	10/4	2200-2300	2.190	68.2
109-S	10/4	1245-1345	2.460	76.2
110-S	10/5	1420-1520	2.450	81.3
111-S	10/5	1605-1705	0.976	63.5
112-S	10/5	1740-1840	0.976	62.7
113-S	10/5	1910-2010	0.936	61.7
114-S	10/10	1145-1235	0.789	25.4
115-S	10/10	1240-1330	0.789	25.4
116-S	10/10	1410-1510	0.762	25.4
117-S	10/11	0805-0905	0.775	25.4
118-S	10/11	1045-1145	0.802	25.4
119-S	10/11	1150-1250	0.735	25.4
120-S	10/12	0645-0745	0.842	40.6
121-S	10/12	0830-0930	0.869	38.1
122-S	10/12	0955-1055	0.816	39.4
123-S	10/12	1115-1215	0.816	63.5
124-S	10/12	1250-1350	0.829	63.5
125-S	10/12	1400-1500	0.789	63.5

To convert from	to	multiply by
liters/m^3	gal/1000 ft^3	7.48
cm W.G.	in. W.G.	3.94 E-1

TABLE 5-6. SCRUBBER EMISSIONS CONCENTRATIONS

OPERATING CONDITIONS (units as noted)						
L/G (liters/m^3)	0.833	0.833	0.833	2.060	2.060	2.060
ΔP (cm W.G.)	25.5	38.0	67.2	25.5	38.0	67.2
Run No.	114,115,117, 118,119	120,121, 122	111,124, 125	107	104,105	108,110
ANALYTICAL RESULTS (mg/dry std. m^3)						
Gravimetric Analysis						
Particulate (in)[a]	615.2 (440-860)[b]	394.9 (370-430)	503.5 (350-650)	422.9	635.3 (510-760)	512.7 (410-610)
(out)	200.9 (120-370)	130.4 (120-150)	99.30 (76-130)	118.5	156.2 (110-210)	128.6 (110-150)
Specific Ion Electrode						
Cl (in)	315 (290-370)	348	640		754 (480-1000)	482 (460-500)
(out)	18.7 (12-26)	13.3	9.89		34.5 (23-46)	7.07 (6-8)
Atomic Absorption Analysis						
Pb (in)	7.08 (4-12)	6.47 (3-11)	5.03 (4-6)	[c]	9.32 (7-11)	3.32 (2-4)
(out)	3.42 (2-5)	4.38 (2-7)	2.24 (2.2-2.3)		4.43 (3-6)	1.70 (1-3)
Cd (in)	.279 (.2-.5)	.349 (.2-.4)	.371 (.37-.38)		.327 (.3-.4)	.165 (.1-.2)
(out)	.141 (.1-.2)	.236 (.1-.3)	.163 (.16-.17)		.260 (.1-.4)	.078 (.05-.1)
Fe (in)	.933 (.5-1.3)[d]	.534 (.3-.8)	.576 (.4-.7)		1.96 (.9-3)[e]	.506 (.3-.7)
(out)	2.81 (.1-8)	.306 (.2-.5)	.324 (.31-.34)		1.48 (1.3-1.7)	.195 (.1-.3)
Cu (in)	.355 (.2-.6)	.294 (.28-.31)	.277 (.2-.3)		.417 (.3-.6)	.201 (.16-24)
(out)	.222 (.1-.3)	.204 (.20-.21)	.111 (.08-.14)		.199 (.1-.3)	.082 (.07-.1)
Zn (in)	21.1 (4-37)	11.3 (9-14)	16.3 (9-24)		39.9 (27-53)	10.2 (7-13)
(out)	9.23 (2-13)	6.91 (5-9)	5.09 (4-7)		10.2 (9-12)	4.25 (3-6)

[a] Front half only.

[b] All emission concentrations within parentheses express the nominal range of emissions. Where ranges are not shown, only one run was reported. Ranges have been rounded and thus cannot be used for statistical evaluation. They are provided to give the reader an idea of the orders of magnitude observed in the results.

[c] Run 107, AA analysis was invalid.

[d] All runs were averaged; however, two of the five indicated negative percent removal for Fe.

[e] Both runs were averaged; however, one run indicated negative percent removal for Fe.

shown in parentheses on Table 5-6 give the order of magnitude of these data.

Test Runs 106, 109, 112, 113, 116, and 123 are not included in this table and are eliminated from all data reduction. All of these tests showed efficiencies of less than 50 percent for particulate removal, and Runs 112, 113, and 116 showed higher concentrations at the outlet than at the inlet. Droplet reentrainment is assumed to have caused this negative percent removal of particulate in these test runs. Figure 5-4 presents particulate removal efficiencies for all scrubber test runs. So that data would not be biased with nonrepresentative tests, all runs having removal efficiencies below 50 percent have been omitted from further evaluation or discussion.

Test Run 107 was the only one made while the L/G was high (2.06 liters/m^3, 15 gal/1000 ft^3) and the pressure drop was low (25.5 cm W.G., 10 in. W.G.). Because equipment design limitations prevented this operating condition from being stable, Run 107 is omitted from further data reduction.

Particulate removal efficiency of the pilot scrubber averaged 71.5 percent. Figure 5-5 presents the particulate removal efficiency as a function of pressure drop. Increased pressure drop appears to produce better removal efficiency. Numbers on the figure indicate the test runs that were averaged to obtain the specific data point. Because occasional reentrainment of droplets from the scrubber occurred and increased L/G makes the chances of reentrainment even greater, definite conclusions could not be

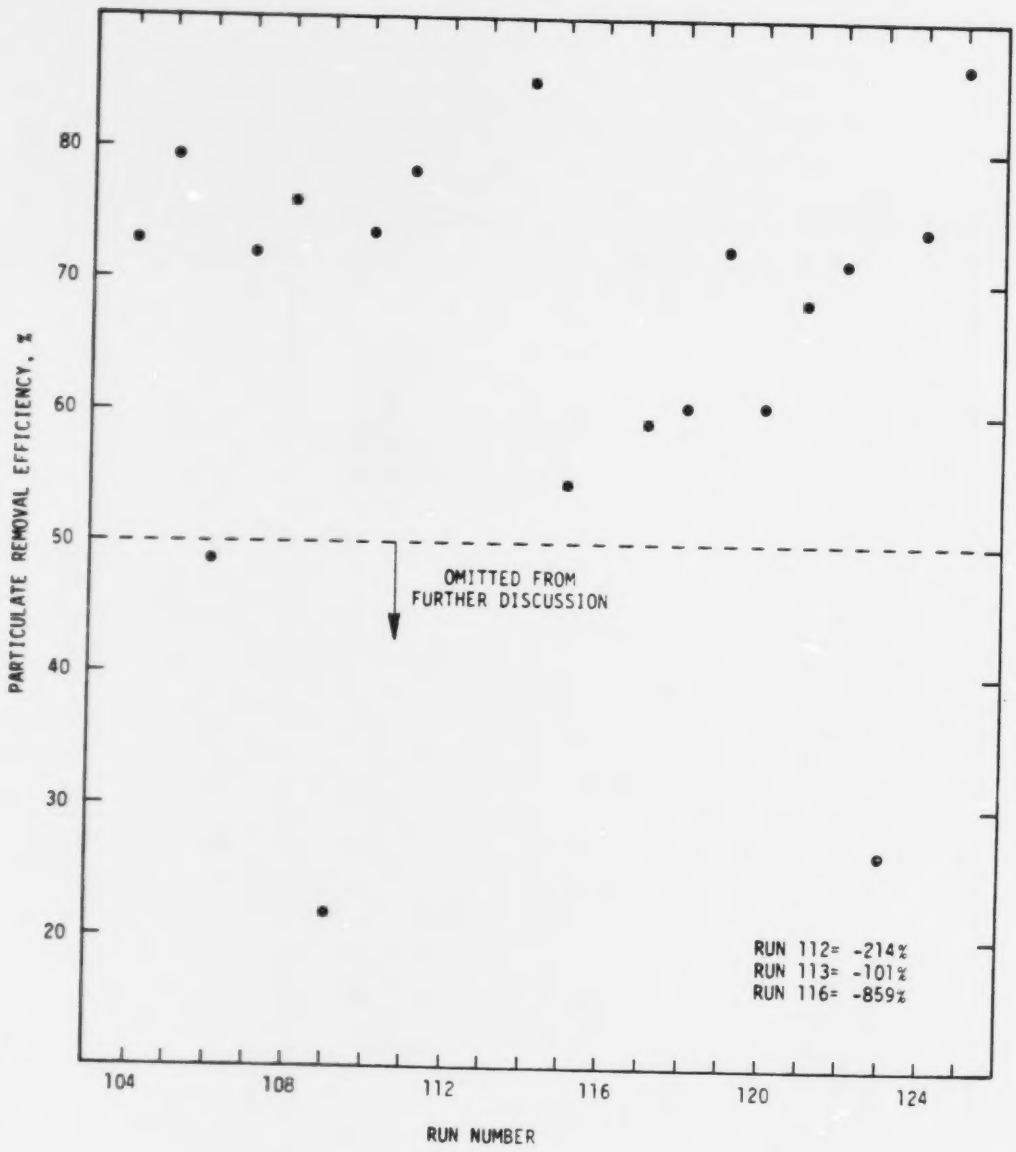

Figure 5-4. Pilot scrubber - particulate removal efficiency for all test runs.

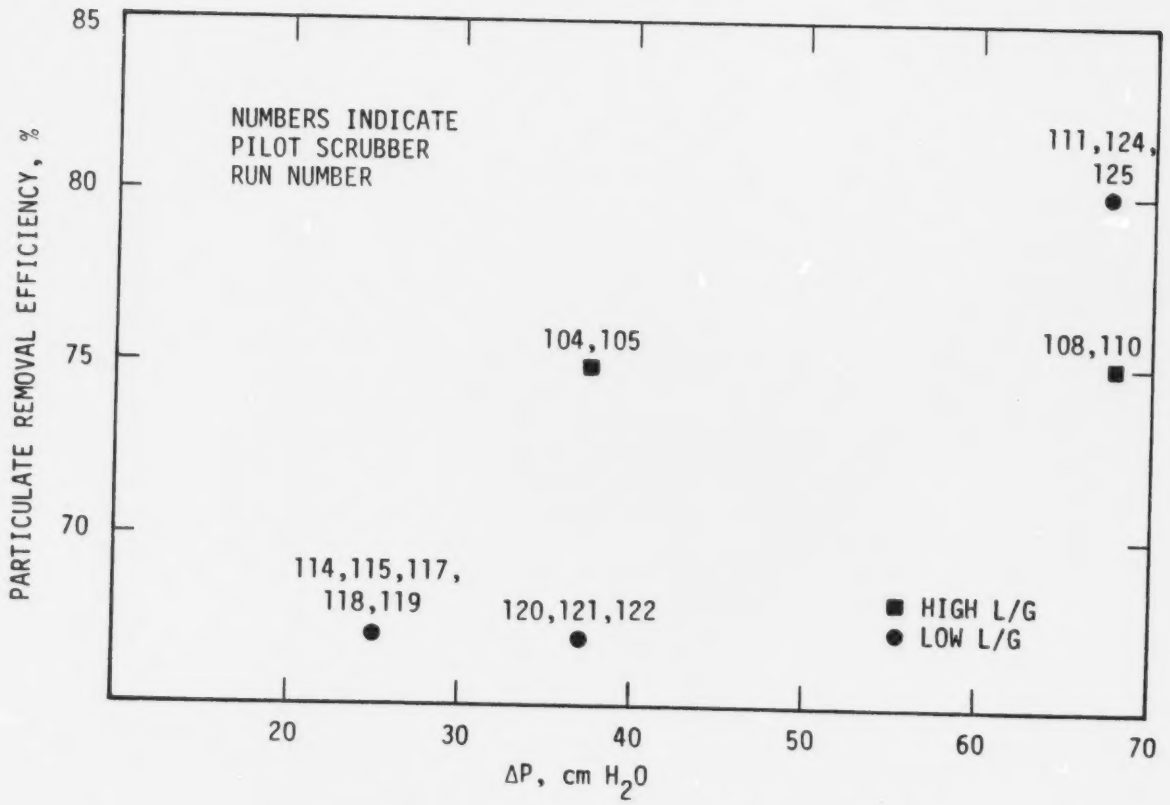

Figure 5-5. Pilot scrubber - particulate removal efficiency as a function of pressure drop.

drawn on the effect of pollutant removal efficiency with increased L/G. In many cases, the higher L/G appeared to provide better particulate removal, although the reverse relationship was also noted (probably as a result of increased reentrainment with high L/G).

Figure 5-6 presents outlet particulate concentration as a function of pressure drop. Outlet particulate concentration decreased with increased pressure drop. Low L/G also seemed to decrease outlet particulate concentration, but this may be explained by the greater potential for reentrainment with higher L/G and is therefore probably not valid.

Figure 5-7 presents chloride removal efficiency as a function of pressure drop. The chloride removal efficiency of the scrubber averaged 96 percent and increased with increased pressure drop. At high pressure drop (ΔP = 67.2 cm W.G.) the chloride removal efficiency was 98.5 percent for both the high and low L/G ratio; however, insufficient data were collected to show a significant trend of the effect of L/G on chloride removal efficiency.

Figures 5-8 through 5-12 show the emissions of lead, zinc, iron, cadmium, and copper concentrations as a function of pressure drop. No metal emission data are available for low pressure drop (ΔP = 25.5 cm H_2O) and high L/G ratio (L/G = 2060 liters/1000 m^3). All data points are average values of the test runs indicated by corresponding run numbers. Both inlet and outlet concentrations

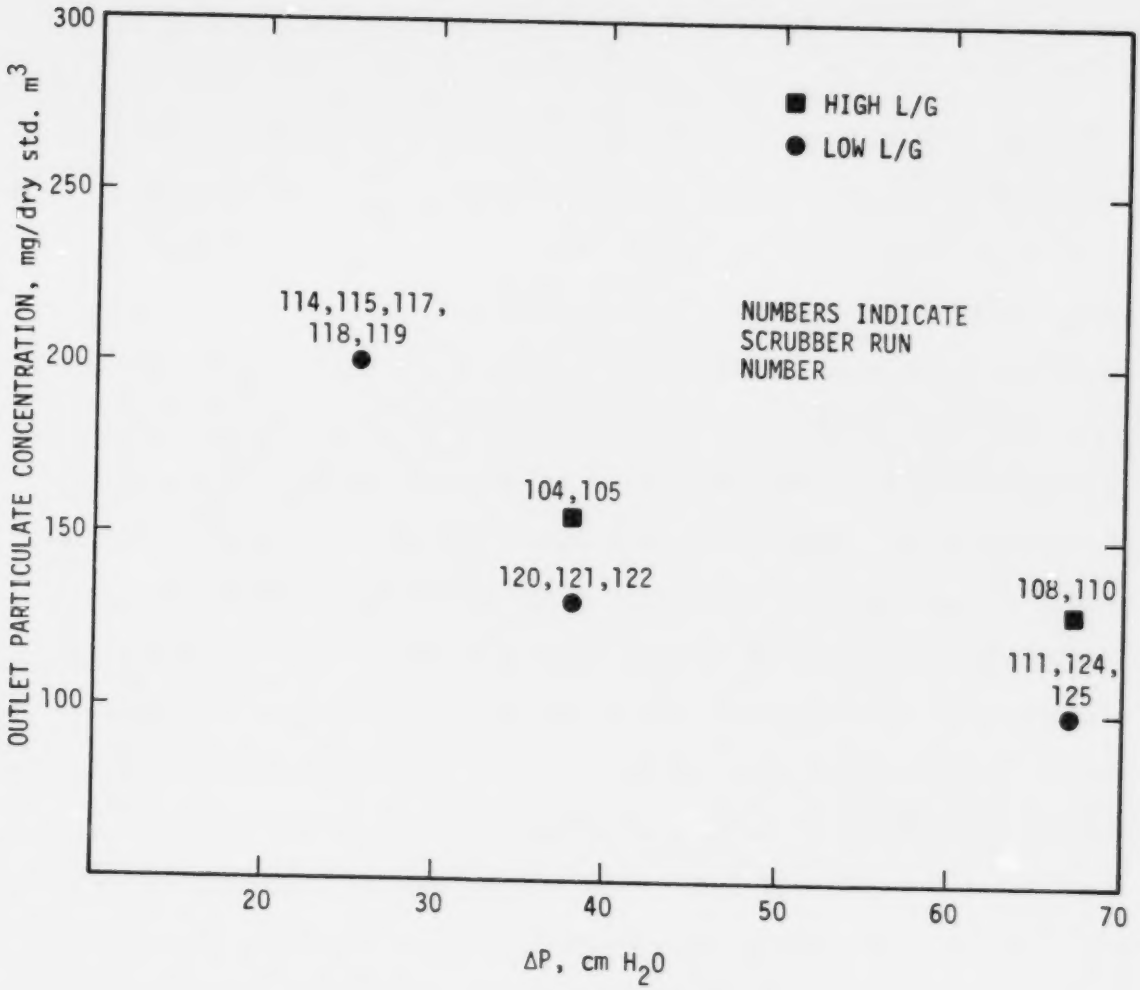

Figure 5-6. Scrubber - outlet particulate concentration as a function of pressure drop.

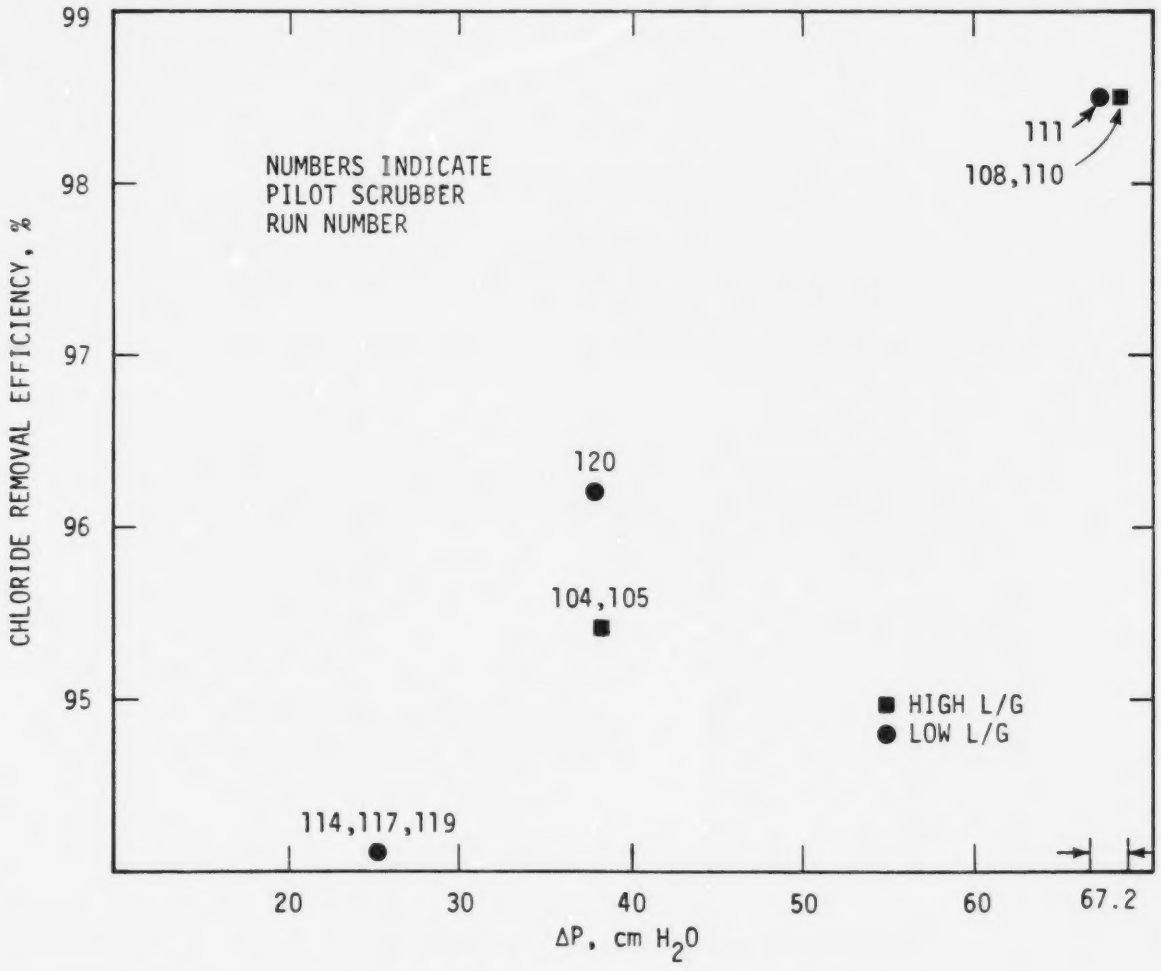

Figure 5-7. Pilot scrubber - chloride removal efficiency as a function of pressure drop.

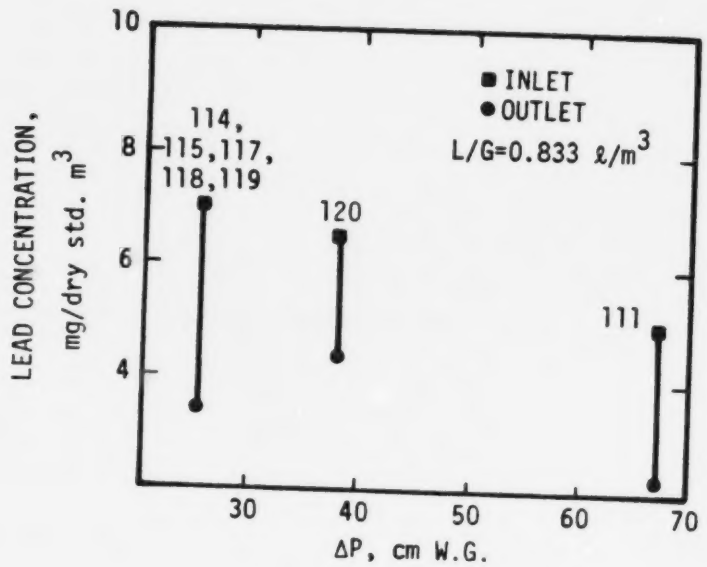

Figure 5-8a. Lead concentration vs. pressure drop (low L/G).

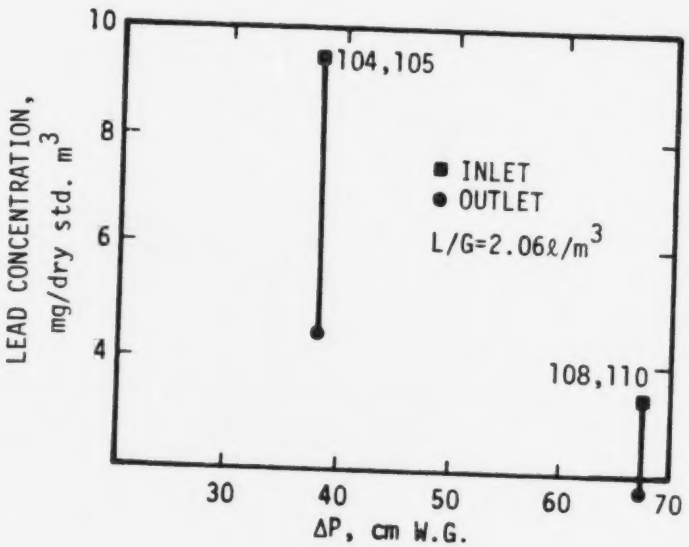

Figure 5-8b. Lead concentration vs. pressure drop (high L/G).

Note: Numbers within each graph indicate scrubber run number.

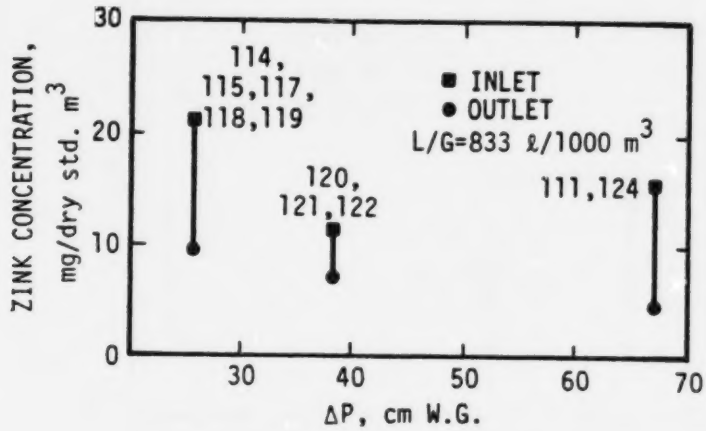

Figure 5-9a. Zinc concentration vs. pressuee drop (low L/G).

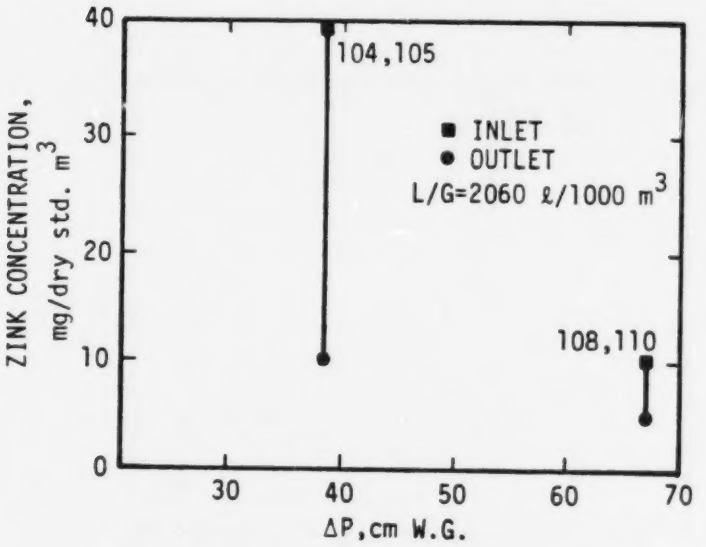

Figure 5-9b. Zinc concentration vs. pressure drop (high L/G).

Note: Numbers within each graph indicate scrubber run number.

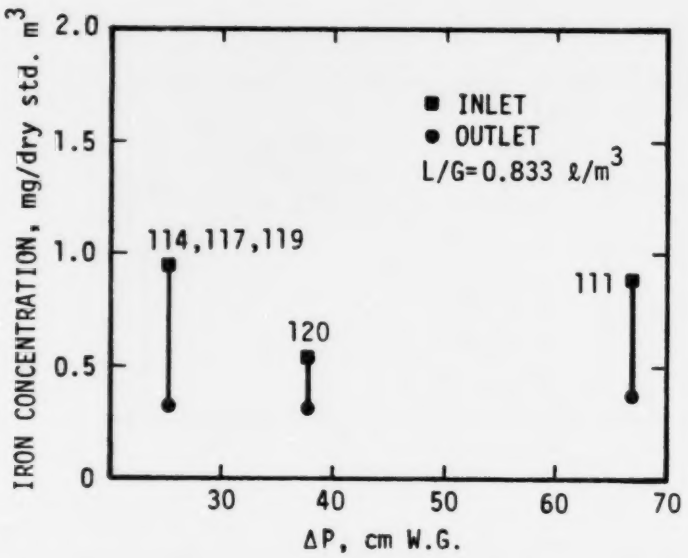

Figure 5-10a. Iron concentration vs. pressure drop (low L/G).

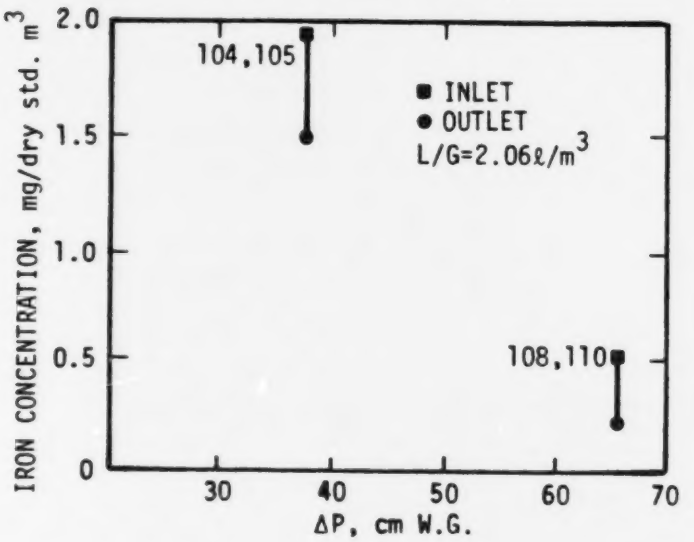

Figure 5-10b. Iron concentration vs. pressure drop (high L/G).

Note: Numbers within each graph indicate scrubber run number.

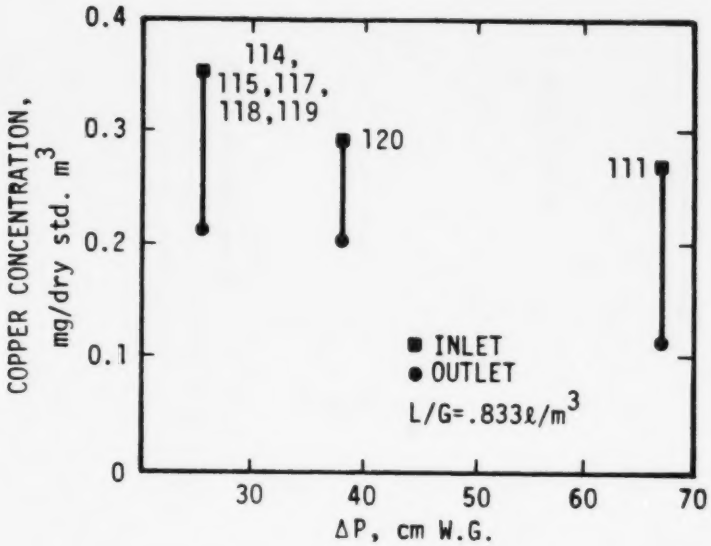

Figure 5-12a. Copper concentration vs. pressure drop (low L/G).

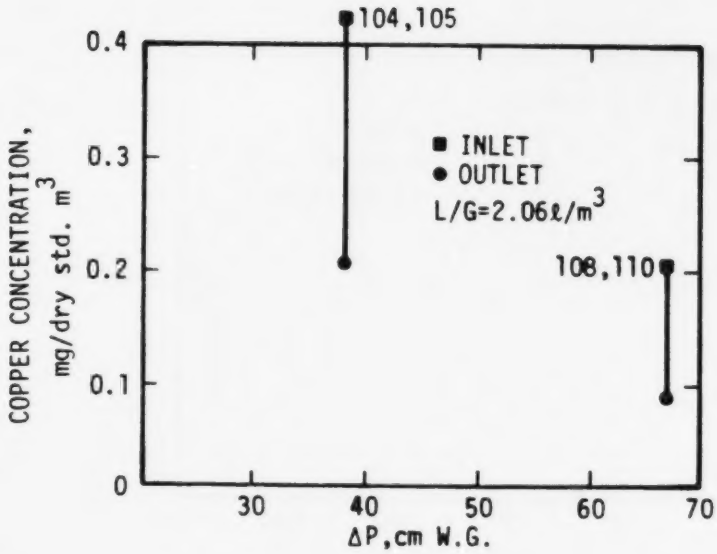

Figure 5-12b. Copper concentration vs. pressure drop (high L/G).

Note: Numbers within each graph indicate scrubber run number.

are presented at the specific L/G. Generally, outlet concentrations decreased with increased pressure drop, and a higher L/G resulted in lower outlet metal emissions.

The removal efficiencies for these specific metals ranged from 20 to 74 percent. (Iron concentration was higher at the outlet than at the inlet on Test Runs 115 and 118. The reason for this is probably sample contamination, and the data were not included in Figure 5-10a.) Also, removal efficiency improved with increased pressure drop; i.e., at 38 cm W.G. pressure drop the average removal efficiency for all metals was 40 percent, and at 67.2 cm W.G. pressure drop, 57 percent. A comparison of low and high L/G conditions did not yield significant differences in removal efficiencies.

Overall, the effectiveness of the scrubber in removing emissions of lead, cadmium, iron, copper, and zinc was in the 40 to 50 percent range. In the medium pressure drop range, removal efficiency increased with increased L/G. They also consistently improved with increased pressure drop.

The scrubber appears to control lead, cadmium, copper, and iron emissions equally well over all operating conditions, but it controls zinc slightly better. The difference is not significant, however, and there is no apparent relationship or consequential trend between the different metals and the control effect of the scrubber.

SECTION 6

QUALITY ASSURANCE

An acceptable level of confidence in the analytical test data was achieved by the implementation of a quality assurance (QA) program, which was applied throughout the entire testing operation. A continuous QA program was an integral part of all phases of sampling and analysis in this project. This section discusses the specific QA procedures, which include the use of standardized reference methods, equipment calibration, performance audits, maintenance of sample integrity, and data validation.

6.1 REFERENCE METHODS

Sampling and analytical methods were based on EPA reference methods. The methods in this test program are discussed in detail in Appendix A. The Federal Register, Vol. 42, No. 160, August 18, 1977, Methods 1-8; Annual Book of ASTM Standards, part 26; and U.S. EPA, Methods for Chemical Analysis for Water and Wastes served as references for the various methods.

6.2 CALIBRATION PROCEDURES

All sampling equipment and analytical instrumentation were calibrated on a regularly scheduled basis. The sampling equipment was calibrated according to the procedures outlined in Maintenance,

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Calibration, and Operation of Isokinetic Source-Sampling Equipment by Office of Air Programs, Publication No. APTD-0576. Analytical instrumentation was calibrated as recommended by manufacturers or, more frequently, as part of the routine laboratory schedule. The following routine described specific details of calibration procedures.

Sampling equipment components that require routine calibration are nozzles, dry gas meter and orifice, thermocouples and temperature readout, and pitot tubes. The nozzles were calibrated by making three separate measurements of the inside diameter with a micrometer and calculating the average. The measurements must agree within 0.051 mm (0.002 inch) for the nozzle to be acceptable. The dry gas meter and orifice are calibrated concurrently as shown in the setup in Figure 6-1. The dry gas meter and orifice were calibrated against a wet test meter with ± 1 percent accuracy. Six discrete comparisons are made by using a range of orifice pressure drops from 1.3 to 10.2 cm H_2O (0.5 to 4.0 inches H_2O). Information is recorded on the form shown in Figure 6-2. The $\Delta H@$, orifice pressure differential that gives 0.021 m^3/min (0.75 cfm) of air at 21°C and 760 mm Hg, is calculated, and each of the six readings must not deviate from the average by more than ± 0.38 cm (0.15 inch). The γ factor, which is the factor of the wet test meter to the dry gas meter, is calculated and the allowable tolerance is ± 1 percent.

All temperature-measuring devices, such as thermocouples with potentiometers and thermometers, are calibrated against a

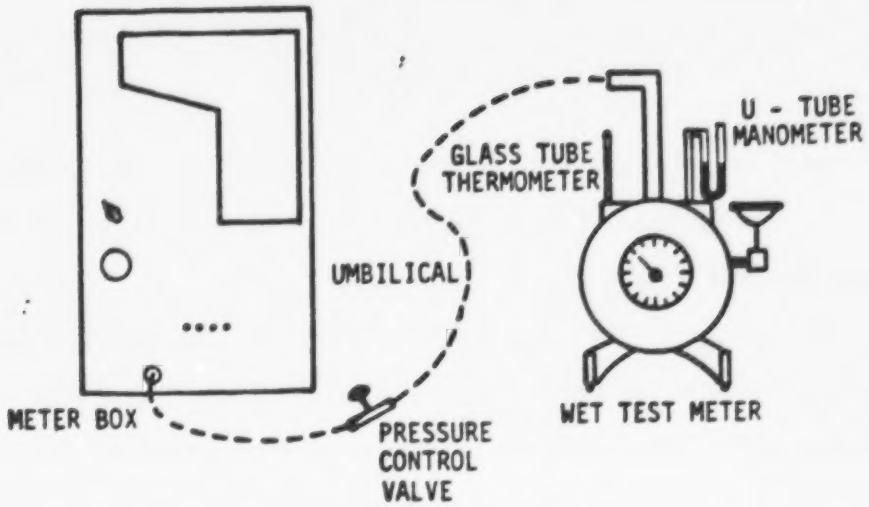

Figure 6-1. Calibration setup.

DATE_____ METER BOX NO._____

BAROMETRIC PRESSURE, P_b = _____in. Hg. DRY GAS METER NO._____

Orifice manometer setting ΔH in. H_2O	Gas volume wet test meter V_w, ft_3	Gas volume dry gas meter V_d, ft_3	Wet test meter t_w, °F	Dry gas meter Inlet t_{di}, °F	Dry gas meter outlet t_{dn}, °F	Dry gas meter Average t_d, °F	Time θ, min	Y	ΔHθ
0.5	5								
1.0	5								
1.5	10								
2.0	10								
3.0	10								
4.0	10								

Average _____

ΔH	$\frac{\Delta H}{13.6}$	Y $\frac{V_w P_b (t_d + 460)}{V_d (P_b + \frac{\Delta H}{13.6}) (t_w + 460)}$	ΔHθ $\frac{0.0317 \Delta H}{P_b (t_d + 460)} \left[\frac{(t_w + 460)\theta}{V_w}\right]^2$
0.5	0.0368		
1.0	0.0737		
1.5	0.110		
2.0	0.147		
3.0	0.221		
4.0	0.294		

Y = Ratio of accuracy of wet test meter to dry test meter. Tolerance = ± 0.01
ΔHθ = Orifice of pressure differential that gives 0.75 cfm of air at 70°F and 29.92 inches of mercury, in H_2). Tolerance = +0.15.

Figure 6-2. Calibration data sheet.

glass mercury thermometer of known accuracy. Pitot tubes are checked to verify that design specifications outlined in EPA Reference Method 2 are met (Figure 6-3).

All analytical instrumentation used in the lab was calibrated according to manufacturers' instructions, and the results were documented. The analytical balance was checked daily with standard weights, and a log was maintained to document its calibration. The specific ion probe with the millivolt meter were calibrated before each use with calibration standards. Control samples were run throughout the analysis to assure that there was no drift in the calibration curve. The atomic absorption spectrophotometer was calibrated with each use, and control samples were also run periodically throughout the analyses.

6.3 PERFORMANCE AUDITS

In addition to the original calibration of all sampling equipment, periodic spot checks were performed for verification of calibrations or for rapid detection of "out-of-control" condition. These checks are referred to as performance audits.

Such an audit was performed routinely on the dry gas meter and orifice. After approximately 10 test runs or whenever sampling equipment was transported or severely jolted, a calibration check was performed by pulling ambient air through the dry gas meter or orifice pressure differential equivalent to the $\Delta H@$ and calculating the volumetric flow rate at 21°C and 760 mm Hg (ambient conditions). The $\Delta H@$ is the orifice pressure differential that was determined at the time of calibration, which

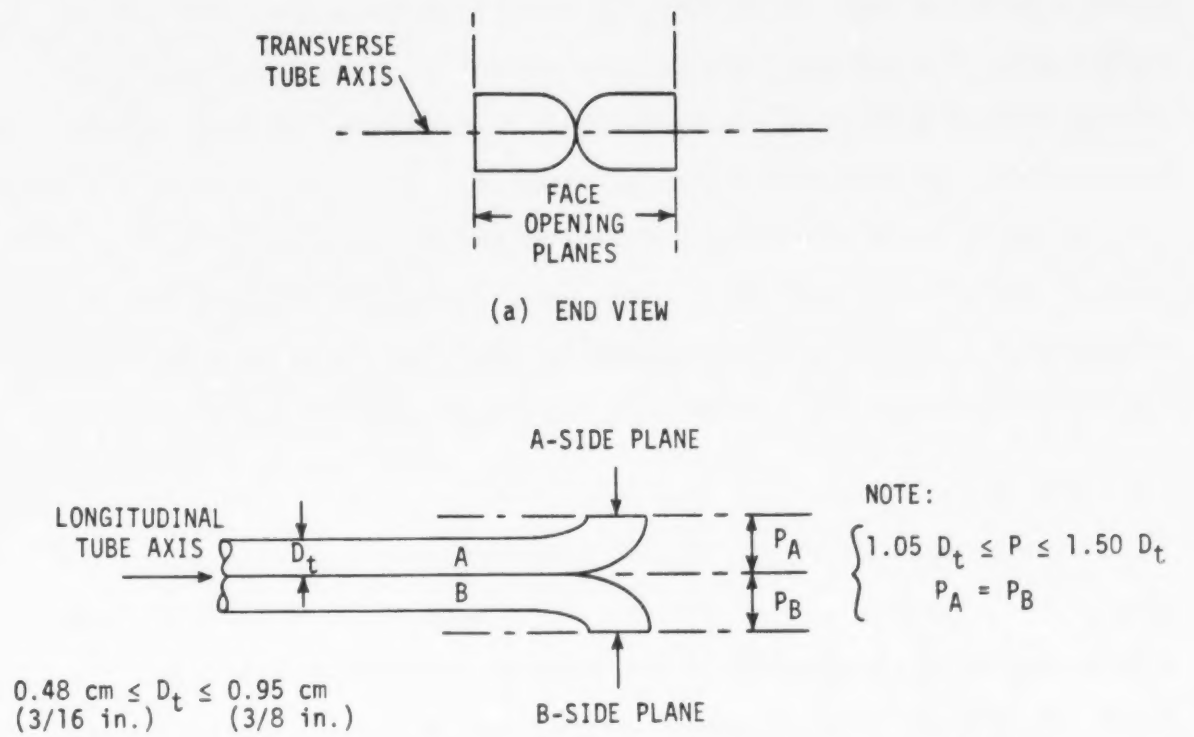

Figure 6-3. Properly constructed Type S pitot tube, shown in: (a) end view; face opening planes perpendicular to transverse axis; (b) top view; face opening planes parallel to longitudinal axis; (c) side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient value of 0.84 may be assigned to pitot tubes constructed this way.

gives a 0.021 m^3/min (0.75 cfm) of air at these conditions. The acceptance limits were 0.021 m^3/min $\pm$0.001 m^3/min, and if these limits were not met the equipment was returned to the laboratory for remedial maintenance and recalibration.

Several field activities were audited for maintenance of quality control. Field data forms were routinely checked for completeness and accuracy, isokinetic sampling rates were verified, and a sample log system was carefully checked daily.

6.4 SAMPLE INTEGRITY

In the maintenance of sample integrity, all aspects of sample handling and record keeping are addressed. Basically, all sample activity is thoroughly documented, including labeling, chain of custody, sample preservation, and storage. This insures proper handling of samples and prevents sample contamination, ambiguous sample labeling, and the collection of improper sample quantities.

6.5 DATA VALIDATION

Precision is defined as the reproducibility of results when replicate measurements are made on a homogenous sample and the same technique, reagents, instruments, and preferably, the same analyst are used. Accuracy is defined as the closeness of a measurement to an accepted or true value.

Randomly selected samples were split after sampling and analyzed by the laboratory as separate, discrete samples. Precision values given in Table 6-1 were calculated as follows:

$$\%d = \left(\frac{A-B}{(A+B)/2}\right) \times 100$$

where %d = percent difference between values A and B.

A = results of analysis of split sample aliquot A.

B = results of analysis of split sample aliquot B.

In addition, randomly selected samples were split and spiked. One portion of the split sample was analyzed as received and to the other portion a known amount of "spike" solution was added. For determination of the accuracy of values shown in Table 6-1, the following equation was used:

$$\%A = 100 - \left(\frac{1m - a1}{a}\right) 100$$

%A = percent accuracy

m = measured value

a = actual value

Another means of quantifying accuracy is to analyze a standard reference material (SRM) obtainable from the National Bureau of Standards along with the samples. One SRM was analyzed, and results are reported in Table 6-1.

TABLE 6-1. RESULTS OF RANDOMLY SPLITTING AND SPIKING SAMPLES FOR ANALYSIS

Precision	
Test	% d
Cl	7.6%
SO_x	3.1%

Accuracy	
Test	% A
Cl	94%
Pb[a]	71%
Zn[a]	36%
Fe[a]	100%

[a]Based on NBS standard.

SECTION 7

TEST SUMMARY

PEDCo conducted tests on the pilot fabric filter and venturi scrubber, which were slipstreamed on uncontrolled flue gas from the Braintree Municipal incinerator over sequential time periods. The fabric filter was operated and tested from August 28 to September 14, 1979 and the venturi scrubber, from October 2 to October 12, 1979. At the time of testing of the two pilot control devices normal operating conditions of the incinerator were maintained and no attempt was made to modify them except as required to retain steady-state conditions throughout the test program. The Braintree Plant operated continuously and was very reliable over the entire test program.

The town of Braintree generates an average of 90 to 93 Mg (95 to 100 tons) of refuse per day. The accounting records of the incinerator (Figure 2-3) yielded the following source characterization data:

Source	Percent
Residential	60.0
Schools	6.3
Other departments and State	2.1
Cars	5.3
Vans and pickup trucks	26.3
	100.0

The Braintree Municipal Incinerator is a mass-burn, water-wall type consisting of two furnaces, each designed to burn 4.7 Mg (5 tons) per hour of unprocessed refuse. Temperatures in the furnace combustion zone are in the order of 1310°C (2400°F), and excess air levels sometimes exceed 400 percent. Flue gas temperatures normally range from 200° to 310°C (400 to 600°F). Exhause gases from the incinerators are directed into individual ESP's. Exhaust gas flow rates from each of the ESP's are in the range of 420 to 710 std. m^3/mi (15,000 to 25,000 scfm). Particulate matter collected by the precipitators is sluiced with water into the incinerator bottom ash quench trough.

The priority project objective was to characterize the pollutant removal efficiencies of each control device under a set of variable operating conditions. It was assumed that any full-scale installation must operate with varying flue gas temperature and fluctuating flue gas compositions that result from variation in waste feed. The experimental plan was to measure and monitor these two factors and perform a test program during "normal" operating conditions.

7.1 PILOT FABRIC FILTER

The pilot fabric filter was operated at the Braintree site August 28 through September 14, 1979, and was tested on 27 runs. The fabric filter was operated with a precoat additive (Minuteman, Type S, Hydrated Lime), which was aspirated into the inlet of the fabric filter, but downstream of the inlet sample port.

During the test program, the A/C ratio was varied from 27.4 to 36.6 m^3/s per m^2 while the gas volume through the fabric filter ranged from 0.20 to 0.26 m^3/s. Because of operational problems due to improper seals around several bag connections at the tube sheet, the first series of tests were not included in the data analysis.

Particulate removal efficiencies averaged 95.1 percent. Increasing the pressure drop increased the particulate removal efficiency but varying the A/C ratio did not seem to effect it significantly over the range tested. At a pressure drop of 11 cm W.G., particulate removal efficiency averaged about 95 percent with an average A/C ratio of 31.1 m^3/h per m^2 and approximately 87 percent with an A/C of 36.0 m^3/h per m^2. On the other hand, particulate-removal efficiencies averaged almost 99 percent at a pressure drop of 14.5 cm W.G. and an A/C of 35.2, but only 97 percent with an average pressure drop of 15.8 cm W.G. and an A/C of 29.2 m^2/h per m^2.

The control of trace element emissions by the fabric filter was effective. Lead removal efficiency averaged 99.5 percent, cadmium and zinc removal efficiencies were over 99 percent, copper emissions were controlled from 95.7 to 99.7 percent and iron emissions control ranged from 88 to 99 percent.

The control of gaseous emissions with the use of lime precoat was not as effective as expected. Chloride and SO_x removal efficiencies were 28 and 37 percent respectively. At Ames, where the concentrations of chloride and SO_x were much different from

those at Braintree, the fabric filter reduced both of these pollutants by about 20 percent. This might indicate that lime precoating effectively removes some gaseous pollutants but further study is needed to verify this effect.

7.2 PILOT SCRUBBER

The venturi scrubber was installed and operated at the Braintree incinerator from October 2 to October 12, 1979. A total of 28 test runs were performed. Two variable scrubber parameters were liquid-to-gas ratio (L/G) and pressure drop across the venturi throat (ΔP). The L/G ranged from 0.789 liter/m^3 (5.9 gal/1000 ft^3) to 2.46 liters/m^3 (18.4 gal/1000 ft^3). The pressure drop ranged from 25.4 cm W.G. (10 in. W.G.) to 81.3 cm W.G. (32 in. W.G.).

Particulate removal efficiency of the pilot scrubber averaged 71.5 percent. Test results indicated that increased liquid-to-gas ratios (L/G) also caused increased reentrainment. As a result, the effect of L/G on particulate removal efficiency could not be determined from these test data. As expected, however, particulate removal efficiency improved with increasing pressure drop. At about 25 cm W.G. the average particulate removal efficiency was 68 percent, at 38 cm W.G. the average efficiency increased to 70 percent, and at 67 cm W.G. the efficiency further increased to 78 percent.

The scrubber appeared to control lead, cadmium, copper, zinc, and iron emissions equally well over all operating conditions during the test program.

Overall, the effectiveness of the scrubber in removing emissions of these metals was in the 40 to 50 percent range. The removal efficiency improved with increased pressure drop; i.e., at 38 cm W.G. pressure drop the average removal efficiency for all metals was 40 percent, and at 67.2 cm W.G. pressure drop, 57 percent. A comparison of low and high L/G conditions did not yield significant differences in removal efficiencies.

The chloride removal efficiency of the scrubber averaged 96 percent and increased with increased pressure drop. At high pressure drop (ΔP = 67.2 cm W.G.) the chloride removal efficiency was 98.5 percent for both the high and low L/G ratio while at the lower pressure drops the removal efficiency averaged about 95 percent. Insufficient data were collected, however, to show a significant trend of the effect of L/G on chloride removal efficiency.

7.3 OVERALL EVALUATION

The fabric filter outperformed the scrubber for all pollutants found in the particulate phase. The scrubber, however, had a much higher removal efficiency for chlorides (96 as compared to 28 percent).

Both particulate and gaseous emissions can be effectively removed from municipal incinerator exhaust stream using state-of-the-art technology. Where chlorides prove to be a problem, a scrubber can be applied downstream of an ESP or fabric filter to control these emissions.

REFERENCES

1. Hall, F., et al. Evaluation of Pilot Scale Air Pollution Control Devices on a Refuse/Coal-Fired Boiler. Draft Report. PEDCo Environmental, Inc. April 1979.

2. Golembiewski, M., et al. Environmental Assessment of Waste-to-Energy Process, Braintree Municipal Incinerator. Midwest Research Institute. December 1978.

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APPENDIX A

SAMPLING AND ANALYTICAL PROCEDURES

SAMPLING PROCEDURE FOR PARTICULATE, HALIDES, SO_x, TRACE METALS

In this test program, sampling procedures followed those described in Method 5 of the Federal Register.*

SAMPLING APPARATUS

The source sampling train used in these tests at inlet/outlet sampling sites meets design specifications established by the Federal EPA and was assembled by PEDCo personnel. It consisted of:

Nozzle - Stainless steel (316) with sharp, tapered leading edge and accurately measured round opening.

Probe - Pyrex glass with a heating system capable of maintaining a minimum gas temperature of 120°C (250°F) at the exit end during sampling.

Pitot tube - Type S pitot tube that meets all geometry standards and is attached to the probe to monitor stack gas velocity.

Filter holder - Pyrex glass with heating system capable of maintaining a filter temperature of approximately 120°C (250°F).

Draft gauge - An inclined manometer made by Dwyer with a readability of 0.025 cm (0.01 inch) H_2O in the 0 to 2.54 cm (1-inch) range is used.

Impingers - Four impingers connected in series with glass ball joints. The first, third, and fourth impingers are of the Greenburg-Smith design, modified by replacing the tip with a 1.27 cm (1/2-inch) i.d. glass tube extending to 1.27 cm (1/2 inch) from the bottom of the flask.

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* Federal Register, Vol. 42, No. 160, August 18, 1977.

Metering system - Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within -15°C (5°F), dry gas meter with 2 percent accuracy, and related equipment to maintain an isokinetic sampling rate and to determine sample volume. The dry gas meter is made by Rockwell and the fiber vane pump is made by Gast.

Barometer - Bourden tube type to measure atmospheric pressure to ±0.25 cm (0.1 inch) Hg.

SAMPLING PROCEDURE

The stack pressure, temperature, moisture, and range of velocity head were measured according to procedures described in the Federal Register.* An average velocity point in the duct was chosen as the single sampling point.

Approximately 200 grams of silica gel was weighed in a sealed impinger prior to each test. Glass fiber filters** 7.62 cm (3-in. diameter) were desiccated for at least 24 hours and weighed to the nearest 0.1 milligram on an analytical balance. One hundred ml of distilled water was placed in each of the first two impingers; for SO_x collection distilled deionized water was replaced by 3 percent H_2O_2. The third impinger was initially empty; and the impinger containing the silica gel was placed next in series. The train was set up with the probe as shown in Figure A-1. The sampling train was checked for leaks at the sampling site before each test run by plugging the inlet to the nozzle and pulling a 38.1 cm (15-in.)-Hg vacuum, and at the conclusion of the test by plugging the inlet to the nozzle and test run. The pitot tube and lines were checked for leaks at the

* Federal Register, Vol. 42, No. 160, August 18, 1977.

** Gelman Type A.

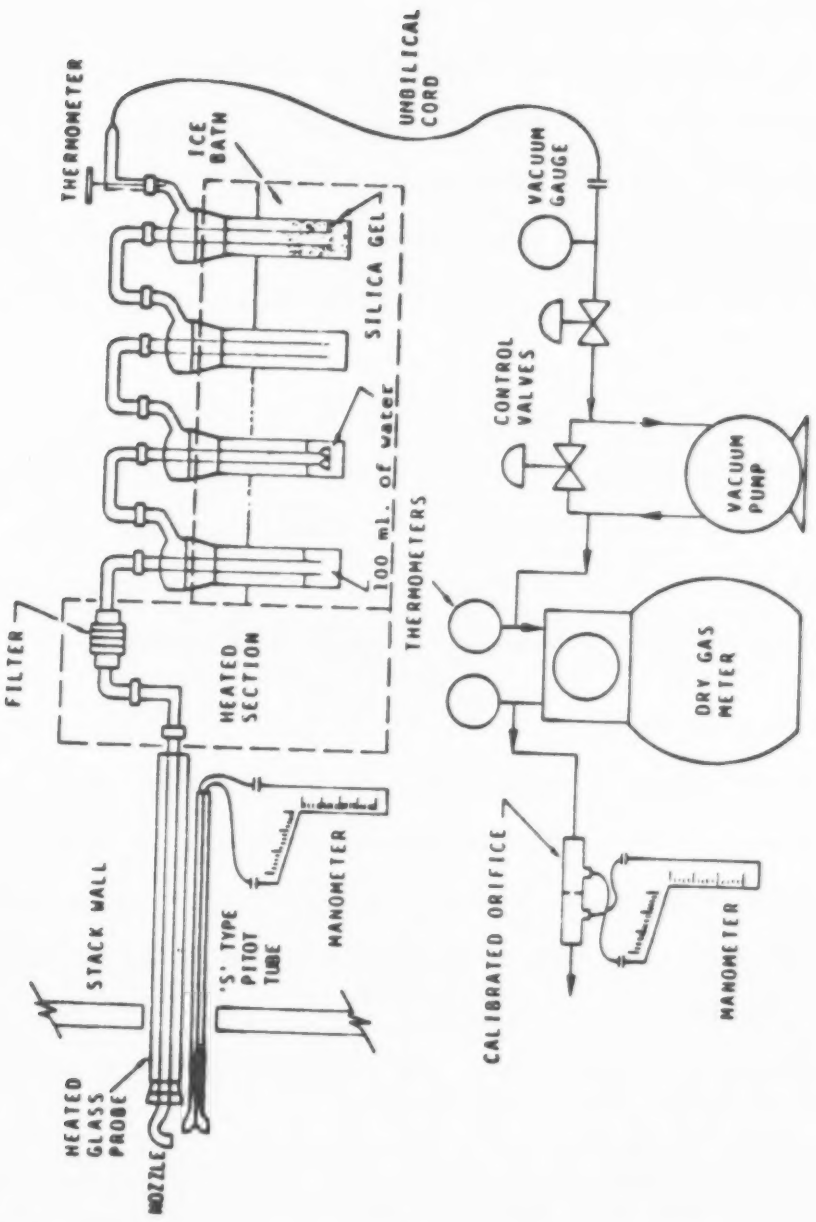

Figure A-1. Sample train.

test site before and after each test run. The check was made by blowing into the impact opening of the pitot tube until 7.62 cm (3 inches) or more of water was recorded on the manometer and then capping the impact opening and holding it for 15 seconds to assure that it was leak-free. The static pressure side of the pitot tube was checked for leaks by the same procedure, except suction was used to obtain the 7.62 cm (3-in.)-H_2O manometer reading. Crushed ice was placed around the impingers to keep the temperature of the gases leaving the last impinger at 20°C (68°F) or less.

During sampling, stack gas and sampling train data were recorded every 10 minutes and when stack flow conditions changed significantly. With the aid of a nomograph, isokinetic sampling rates were set throughout the sampling period. All sampling data were recorded on an emission testing field data sheet.

SAMPLE RECOVERY PROCEDURE

The sampling train was carefully moved from the test site to the cleanup area. Samples of the acetone used in the sample recovery were taken for use as blanks. The volume of water from the first three impingers was measured. Sample fractions were recovered as follows:

Container No. 1 - The filter was removed from its holder, placed in a petri dish, and sealed.

Container No. 2 - Loose particulate and acetone washings from all sample-exposed surfaces prior to the filter were placed in a glass jar, sealed, and labeled. Particulate was removed from the probe with the aid of a brush and acetone rinsing. The liquid level was marked after the container was sealed.

Container No. 3 - The collected volume of liquid in the impingers was measured and recorded. The total catch was placed in a plastic bottle along with distilled deionized water rinse of all glassware following the filter. The liquid level was marked after the bottle was sealed.

Container No. 4 - A minimum of 200 ml of acetone was taken for the blank analysis. The blank was obtained and treated in a similar manner as the acetone washing.

Container No. 5 - 200 ml of 3 percent H_2O_2 was taken from the same batch of H_2O_2 solution used in sampling. This was labeled the H_2O_2 Blank for SO_x analysis with the samples.

The silica gel from the fourth impinger was weighed and recorded on the sample recovery and integrity data sheet with other pertinent data.

ANALYTICAL PROCEDURES

The procedures used follow the methods described in the Federal Register.*

Container No. 1 - The filter and any loose particulate matter from this sample container were placed into a tared glass weighing dish, desiccated for 24 hours to a constant weight, and weighed to the nearest 0.1 mg. The filter was then sectioned with a template. One section of the filter was digested in concentrated HNO_3 and analyzed for various metals by atomic absorption analysis. The other section was stored for later use.

Container No. 2 - The acetone washings were transferred to a tared beaker and evaporated to dryness at ambient temperature and pressure, desiccated for 24 hours to a constant weight, and weighed to the nearest 0.1 mg.

Container No. 3 - The impinger catch was brought to a total volume of 1000 ml with distilled deionized water. The impinger catch was analyzed either for halides or SO_x. For halides, the samples were split, and one portion was analyzed for fluoride (analysis procedure in Method 13B of the Federal Register*). The remaining portion was analyzed for chloride and bromide (ESP and scrubber only) by use of a specific ion electrode in conjunction with a millivolt meter. The analytical procedure for analyzing for SO_x was a barium perchlorate titration (Method 6 of the Federal Register*).

*Federal Register, Vol. 42, No. 160, August 18, 1977.

Container No. 4 - The acetone blank was transferred to a tared beaker and evaporated to dryness at ambient temperature and pressure. The blank was then desiccated for 24 hours to a constant weight and weighed to the nearest 0.1 mg.

Container No. 5 - The H_2O_2 blank was brought to a total volume of 1000 ml with distilled deionized water. The sample blank was analyzed along with the samples for SO_x.

The term "constant weight" means a difference of no more than 0.5 mg or 1 percent of total weight less tare weight, whichever is greater in two consecutive readings, with no less than 6 hours of desiccation between weighings. All analytical data were recorded on analytical particulate data sheets. Acetone blank data were recorded on sheets supplied for this purpose.

SAMPLING PROCEDURE FOR Hg EMISSIONS

The following method was used for collection of mercury samples at inlet/outlet sites of the control devices. The sampling procedure is based on Method 101 of National Emissions Standards for Hazardous Air Pollutants.

SAMPLING APPARATUS

The Hg sampling train used in these tests meets design specifications established by the Federal EPA and was assembled by PEDCo personnel. It consists of:

Nozzle - Stainless steel (316) with sharp, tapered leading edge and accurately measured round opening.

Probe - Pyrex glass with a heating system capable of maintaining a minimum gas temperature of 120°C (250°F) at the exit end during sampling.

Pitot tube - Type S pitot tube that meets all geometry standards, attached to the probe to monitor stack gas velocity.

Filter holder - Pyrex glass with heating system capable of maintaining a filter temperature of approximately 120°C (250°F).

Draft gauge - An inclined manometer, made by Dwyer, with a readability of 0.025 cm (0.01 inches) H_2O in the 0 to 2.54 cm (1-inch) range.

Impingers - Four impingers connected in series with glass ball joints. The first, third, and fourth impingers are of the Greenburg-Smith design, modified by replacing the tip with a 1.27 cm (1/2-inch) i.d. glass tube extending to 1.27 cm (1/2 inch) from the bottom of the flask.

Metering system - Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within -15°C (5°F), dry gas meter with 2 percent accuracy, and related equipment to maintain an isokinetic sampling rate and to determine sample volume. The dry gas meter is made by Rockwell and the fiber vane pump is made by Gast.

Barometer - Bourden tube type to measure atmospheric pressures to ±0.25 cm (0.1 inch) Hg.

SAMPLING PROCEDURE

The stack pressure, temperature, moisture, and range of velocity head were measured according to procedures described in the Federal Register.*

Approximately 200 grams of silica gel are weighed in a sealed impinger prior to each test. A hi-purity glass fiber filter** 7.62 cm (3-in.) diameter was placed ahead of the impingers. One hundred ml of 4 percent $KMnO_4$/10 percent H_2SO_4 was placed in each of the three impingers; and the impinger containing the silica gel was placed next in series. The train was set up with the probe as shown in Figure A-2. The sampling train was checked for leaks at the sampling site before each test run by plugging the inlet to the nozzle and pulling a 38.1 cm (15-inch)-Hg vacuum, and at the conclusion of the test by plugging the inlet to the nozzle and pulling a vacuum equal to the highest vacuum reached during the test run.

The pitot tube and lines were checked for leaks at the test site before and after each test run. The check was made by blowing into the impact opening of the pitot tube until 7.62 cm

* Federal Register, Vol. 42, No. 160, August 18, 1977.

** Gelman Spectrograde.

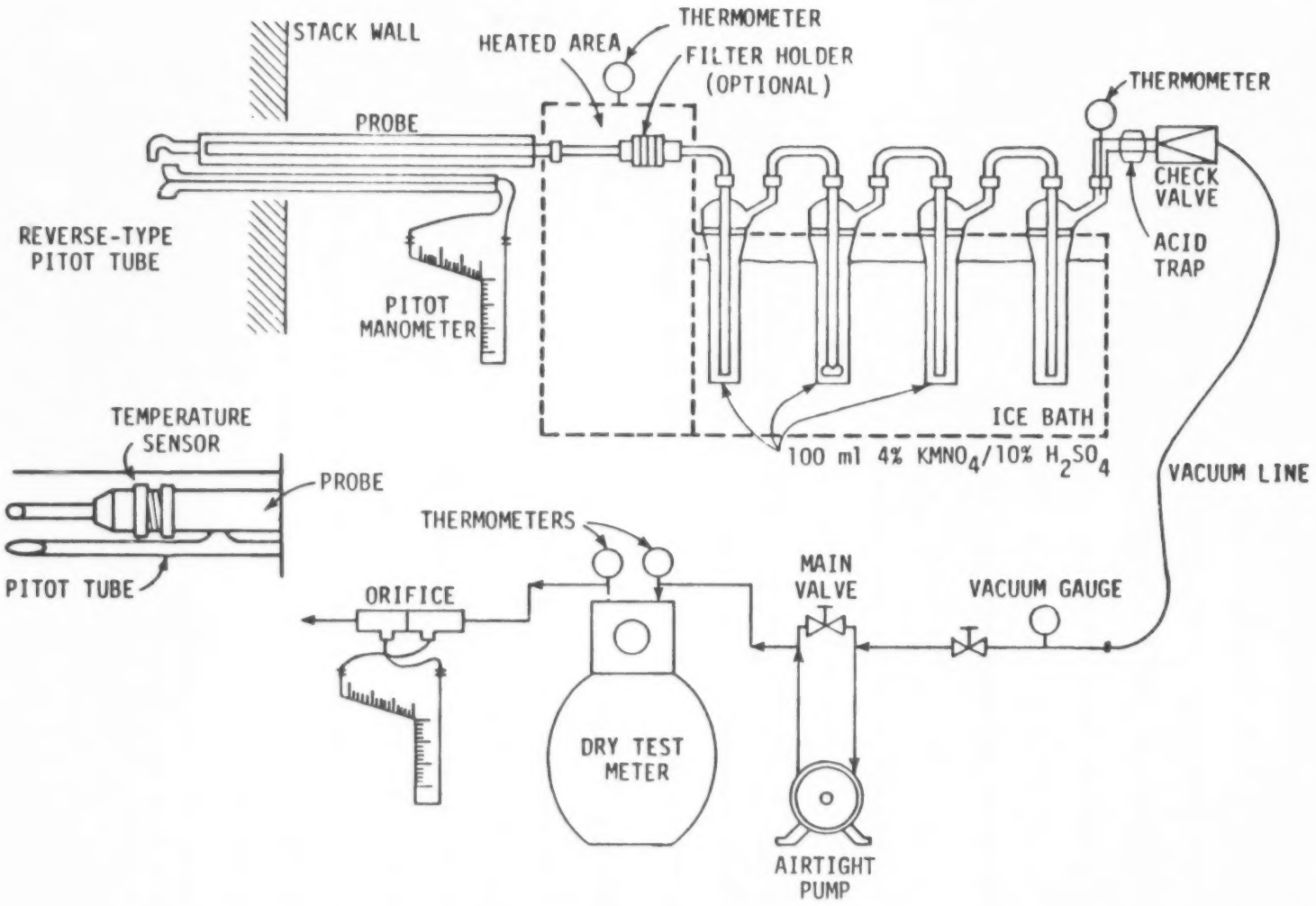

Figure A-2. Sample train for mercury.

(3 inches) or more of water was recorded on the manometer and then capping the impact opening and holding it for 15 seconds to assure it was leak-free. The static pressure side of the pitot tube was checked for leaks by the same procedure, except suction was used to obtain the 7.62 cm (3-in.)-H_2O manometer reading. Crushed ice was placed around the impingers to keep the temperature of the gases leaving the last impinger at 20°C (68°F) or less.

During sampling, stack gas and sampling train data were recorded every 10 minutes and when stack flow conditions changed significantly. With the aid of a nomograph, isokinetic sampling rates are set throughout the sampling period. All sampling data were recorded on an emission testing field data sheet.

SAMPLE RECOVERY PROCEDURE

The sampling train is carefully moved from the test site to the cleanup area. Samples of the 4 percent $KMnO_4$/10 percent H_2SO_4 used in the sample collection were taken for use as blanks, along with a glass fiber filter from the same batch as that used for collection of the samples. The volume of liquid from the first three impingers was measured. Sample fractions are recovered as follows:

Container No. 1 - Entire catch was placed in an acid-washed Wheaton bottle. This included filter, impinger catch, and probe rinse, which were rinsed with the oxidative impinger solution. The residue that adhered to the walls of the glassware was recovered with 8N HCL and distilled deionized water rinse.

Container No. 2 - 300 ml of the 4 percent $KMnO_4$/10 percent H_2SO_4 impinger solution and a blank filter were placed in an acid-washed Wheaton bottle. The filter must be from the same batch as the filters used in sampling.

The silica gel from the fourth impinger is weighed and recorded on the sample recovery and integrity data sheets, along with other pertinent data.

ANALYTICAL PROCEDURES

Both Containers 1 and 2 were analyzed for mercury by flameless atomic absorption (FAA). Sample preparation requires filtering the sample, digesting the filterable residue with concentrated nitric acid, filtering the digested sample, combining the filtrates, bringing the sample to a known volume, and analyzing with cold vapor atomic absorption. Method of standard addition is required to confirm that matrix effects have not interfered with analysis.